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THIRD QUARTERLY REPORT

Period 1 January 1963 - 31 March 1963

RESEARCH AND DEVELOPMENT OF AN OPEN-CYCLE FUEL CELL SYSTEM

0148502

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Defense Products Division
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FOREWARD

This report was prepared by the Space and Defense Sciences Department, Research Division, Allis-Chalmers Manufacturing Company, Milwaukee, Wisconsin under NASA Contract NAS8-2696. The work was administered under the direction of the Electrical Components and Power Supplies Section, Astrionics Division, NASA, Huntsville Alabama. Mr. Eugene Cagle is the technical supervisor for NASA.

This Third Quarterly Report covers the work completed from 1 January 1963 to 31 March 1963 and is submitted as per the 8 February 1963 Contract Modification.

Management direction at Allis-Chalmers includes Mr. Will Mitchell, Jr., Director of Research and Dr. Powell Joyner, Mr. D. T. Scag and Mr. W. W. Edens, Assistant Directors of Research. The project is supervised by J. L. Platner, Section Head and P. D. Hess, Chief Engineer. The Project Leader is D. P. Ghere.

The report was written by R. Opperthauser, D. Ghere, J. Platner, J. Euclide, and J. Rubenzer, e [1963] onfs

Dr. R. Jasinski and Mr. J. Huff are consultants for the gas chromatography analysis.

ABSTRACT

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Theoretical and experimental studies have been directed toward the development of the Vapor Pressure Control technique for the removal of by-product water from hydrogen-oxygen fuel cells.

Investigations of cell performance over extended periods of time were made on single cell units using the gas chromatograph and on multi-cell modules.

Initial tests on various major components necessary to operate and control a breadboard system utilizing Vapor Pressure Control and recirculated reactants are reported.

AUTHOR

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1.0 SUMMARY

A series of operational tests on a single cell operating with Dynamic Vapor Pressure Control has been completed. The gas chromatograph was used to determine steady-state conditions for various combinations of load, condenser temperature, and excess reactant flow rate. The data from all tests has been reduced and plotted by the computer and initial evaluation has been made. A list has been compiled of tests to be rerun and additional tests in areas of interest.

During the multi-cell module tests it was noted that a gradual increase in water vapor pressure in the inlet reactants was necessary to maintain rated cell performance. A series of tests showed that the wax used for sealing the cell was reacting with the KOH in the electrolyte. Elimination of wax from the cell appears to have eliminated the problem.

The three eight-cell modules tested during this quarter confirmed the superiority of the improved internal reactant manifolding first tried during the last quarter.

Under a contract extension received this quarter, testing was started on components for a breadboard system. Initial tests were conducted on several types of pumps and gas-water separators for the gas recirculation system, and on circulating pumps and mixing valves for the coolant system.

2.0 INTRODUCTION

The two previous quarterly reports described the theory of Vapor Pressure Control and the experiments conducted to support this theory and further develop the method of control.

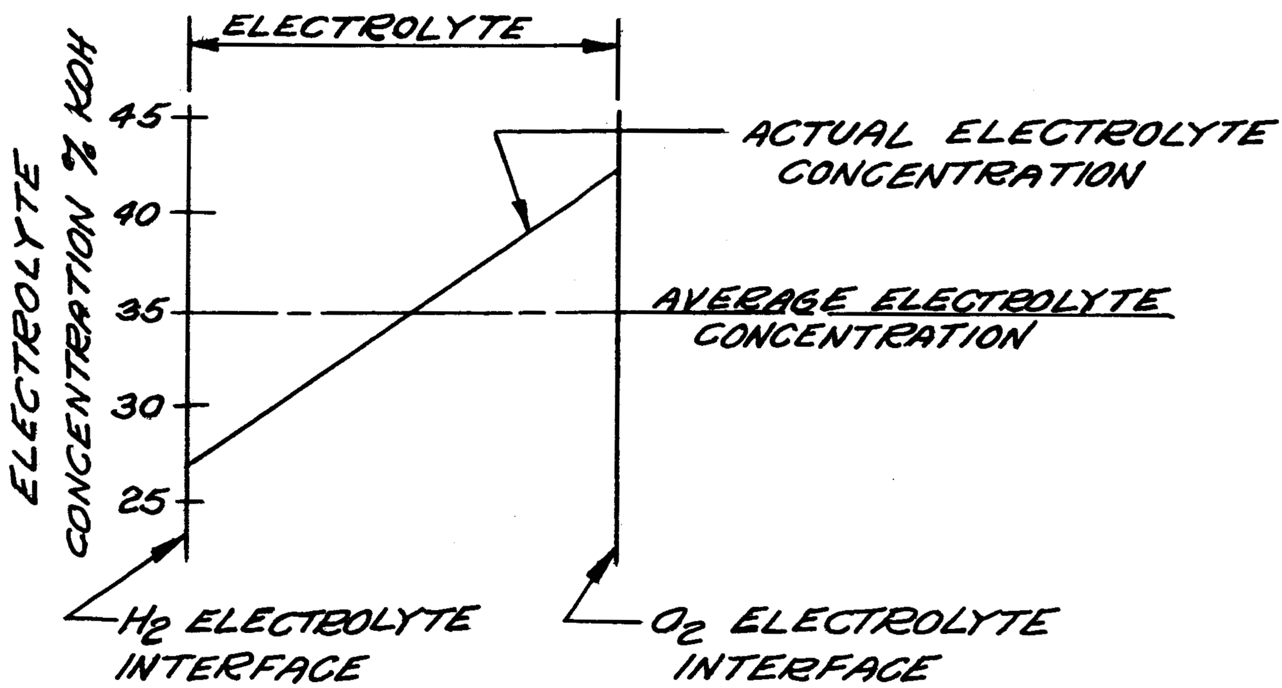
This report describes the continued experimental investigations of the parameters of control and also reports on tests of components necessary to construct a breadboard system employing Vapor Pressure Control. The component development work is being done under an extension of the original contract which was received during this quarter.

3.0 DYNAMIC VAPOR PRESSURE CONTROL TESTS

3.1 Gas Chromatograph Tests

All the fuel cells operated on the gas chromatograph set-up to date have contained 420 cm^2 of active area. The electrolyte vehicles have been impregnated with 30 ml of 35% KOH electrolyte. It is planned to hold these parameters constant through the complete series of the vapor pressure tests. The gas reactant manifolding was changed to an improved design early in the testing program.

The gas chromatograph tests were designed to compare actual cell operation with the predicted cell operation based on the theory of Vapor Pressure Control. The predicted wet and dry limit curves shown on Figure 1 are based on the 27% - 45% electrolyte concentration control band mentioned in previous reports. These values are average concentration in the cell and do not take into account any electrolyte gradients existing across the cell. An electrolyte concentration gradient between the hydrogen and oxygen sides of the cell was observed on all tests. This gradient is illustrated below.



The magnitude of this gradient varied between 3% and 25% KOH depending on cell load and hydrogen flow rate. Since a given condenser temperature and a given ratio of excess hydrogen flow to consumed hydrogen flow would produce a specific steady state electrolyte concentration at the hydrogen-electrolyte interface, the average electrolyte concentration would be higher than the interface concentration because of the gradient effect. With this in mind, the conditions of condenser temperature and hydrogen flow ratio for the chromatograph tests, marked "X" on Figure 1, were chosen so that the resultant average electrolyte concentration within the cell would fall in or near the area bounded by the wet and dry limit curves. Loads of 20, 40 and 60 amps, which are equivalent to 47.6, 95.3 and 143 ma/cm^2, were run at each of these sets of conditions, in order to rigorously test the Vapor Pressure Control theory.

In order to permit better utilization of technical personnel and increase the speed and accuracy of the test results, a program for processing the data has been worked out with the Allis-Chalmers computer facilities. This program digests the raw data, performs calculations, and plots the desired information.

Figure 2 is a copy of a typical test curve as plotted by the computer. The voltage ratio, curve "R", is a ratio of the actual cell voltage to the maximum cell voltage ever observed on that cell at that load. This value will be used to correlate the cell performance with other cells tested. The water removal curve ("W") is calculated as grams of water removed per gram of recirculated or excess hydrogen. This value is found from the difference between the hydrogen outlet and hydrogen inlet water content as measured by the gas chromatograph. Other curves plotted and the symbols used for each are shown in the lower right hand corner of Figure 2. For this report, the curves of equivalent percent KOH were drawn in to facilitate identification.

The various parameters of each test are thus plotted on one sheet against time. The individual test curves obtained in this manner are then evaluated and appropriate data used to plot families of curves for a complete test series.

The data reduction and plotting work on the computer has been completed through Test No. 77. From preliminary evaluation of these plots, a list for future testing has been compiled. This list includes tests which must be rerun and tests in areas of interest found during previous testing. The results of the cell performance tests covered below will probably necessitate additional retesting. It is estimated that this group of experiments should be completed during the next quarter, probably within four weeks.

Figures 2 through 5 are curves from a representative group of tests. The following conditions were held constant during all four tests:

Cell temperature - 93°C
Cell pressure - 2 atmospheres
Load - 20 amperes (47.6 ma/cm^2)
H_2 condenser temperature (simulated) - 65° C

The inlet O_2 flow was not humidified because only enough excess O_2 was passed through the cell to enable samples to be taken for the chromatograph. Excess H_2 flow through the fuel cell was varied as follows:

Test No. 45 - 20 times theoretical consumed
Test No. 46 - 15 times theoretical consumed
Test No. 47 - 10 times theoretical consumed
Test No. 48 - 5 times theoretical consumed

The average operating characteristics of the cell when at equilibrium are summarized in the following table:

Test No.	Equivalent % KOH				Cell Volts
	H_2 In	H_2 Out	O_2 Out	Gradient (H_2 - O_2)	
45	45	39	46	7	.88
46	44	36	44	8	.89
47	44	34	45	11	.90
48	43	29	43	14	.90

This data illustrates and confirms several considerations in operating the cell. With all other operating parameters held constant, note the gradual dilution of the electrolyte, as indicated by the equivalent % KOH of the H_2 out, as the excess flow is decreased. This has another effect, that of increasing the gradient of electrolyte between the hydrogen and oxygen sides. Another interesting point is the increase in voltage as the electrolyte on the H_2 side of the cell goes from a relatively high concentration of 39% (42% average) to a lower concentration of 29% (36% average). A corresponding drop was noted in other tests run at concentrations below 29%. This illustrates the 27% - 45% KOH control band mentioned in previous reports.

Test No. 45 also shows a drying condition very well. At the start of the test the cell was very wet from a previous run in which the reactant gases were dead-ended and no moisture was removed from the cell. Test No. 45 shows how this moisture was removed over a three-hour period, until equilibrium was approached.

In analyzing the data from past tests, certain improvements in testing apparatus were found to be desirable. One of the major problems was in keeping a uniform simulated condenser temperature. Since it has not been necessary to humidify the oxygen on the single cell units due to the low oxygen flow rates, the water bath was removed from the oxygen system and put in series with the bath in the hydrogen system. Temperature fluctuations are reduced and saturation of the gas is assured. An area in which more accuracy was found to be necessary was in measuring the recirculated hydrogen flow rate. A more sensitive capillary tube flow meter was installed and calibrated in the system. Excessive load fluctuation, in the 40 - 60 ampere range, was corrected by installation of a new system of loading.

Changes in testing procedure were made to reduce the disrupting effect of changing the flow between tests. The changes should also shorten the testing time and increase the accuracy of various measurements. A more complete analysis of the test results will be presented after the necessary test reruns and additional tests have been completed and evaluated.

3.2 Cell Performance Tests

As mentioned in previous reports on module testing, a gradual decline in cell performance had been noted with operating time. Further investigation showed a corresponding increase in water vapor pressure in the inlet reactants was necessary to maintain rated performance.

In view of the necessary increase in vapor pressure, a likely cause of the decline seemed to be a reduction of KOH in the electrolyte. Since the Vapor Pressure Control system operates to maintain an essentially constant concentration of electrolyte at a given load, a sufficient reduction in KOH would reduce the quantity of electrolyte to the point that the gas-electrolyte interface would start to recede from the electrode. An increase in the inlet reactant vapor pressure would then add water to the electrolyte, increasing the quantity of electrolyte, thus moving the interface back into the electrode but decreasing the electrolyte concentration.

There were several possible ways in which the amount of KOH in the electrolyte could be reduced. A series of tests was planned and run on the gas chromatograph test set-up in order to try to pinpoint the source or sources of the difficulty. Figure 6 shows the results of these tests on an enlarged scale in order to better illustrate the effects noted. All tests were run at uniform conditions and uniform construction except as noted on Figure 6 or in the following test summaries:

Cell No. S-7

This cell was built with standard electrodes and a waxed asbestos in the same manner as previous tests. All water removed from the cell was collected and analyzed for electrolyte, catalyst and carbonates. The results of the water analysis, Figure 7, showed no removal of KOH or catalyst in the reactant gases.

Cell No. S-9

When Cell S-7 was inspected after running, it appeared that the wax had been forced slowly out of the cell, enlarging the volume available for electrolyte. Cell S-9 was built like Cell S-7 except with a gasket around the waxed portion of the asbestos. This caused a definite improvement, however, a gradually increasing vapor pressure was still necessary.

Cell No. S-10

This cell was built the same as Cell S-9 except a larger quantity of catalyst was used on both electrodes. It was still necessary to periodically increase the vapor pressure to maintain performance.

Cell No. S-11

This cell was built with standard electrodes and the same quantity and concentration of electrolyte as all other cells, but without any wax in the asbestos. A direct seal was effected with the wetted asbestos. A gasket was placed around the outer edges of the asbestos to prevent the sealing edges of the asbestos from drying. This cell showed a variation of about 0.02 volts or less than 2-1/2%, during 85 hours of testing. It was not necessary to increase the vapor pressure at any time during this test.

The above tests indicated that the problem could be attributed to a reaction of the KOH with the wax. Additional chemical tests confirmed that the wax was slowly reacting with the KOH. Future cells will be sealed directly against the wetted asbestos.

3.3 Eight Cell Module Tests

The purpose of these tests is to correlate Vapor Pressure Control theory with module operation. The inter-relating parameters of reactant flow rates, condenser temperatures and fuel cell loads are also being investigated.

During this quarter, three eight-cell modules with active cell areas of 420 cm^2 were tested. All modules incorporated the design changes in the internal reactant manifolding which was initially tested in a four-cell module during the second quarter (Second Quarterly Report, Section 4.2.2). Cell performance and control response was considerably improved by the more uniform flow and gas distribution resulting from the modification. This manifolding will be used in all future testing.

The modification also resulted in a lower pressure drop through the cell which may make an axial fan practical for recirculating the reactant gases through the system. Initial tests on an axial fan are covered in the section on Component Development.

The necessity of continually increasing water vapor pressure in the inlet reactant gases as the operating time of the module progressed was observed on all previous module tests. These observations prompted the cell performance tests reported above.

Although these modules were of the type of construction using wax for a sealant, the results of the test were valuable in evaluating the new internal manifolding and in studying the operation of multi-cell modules operating with Vapor Pressure Control. The reaction of the wax with the KOH is a very gradual process and only becomes a serious problem after about 75 hours of operation.

The first eight-cell module tested during this quarter was operated at various loads for 122.8 hours. During the first 91.8 hours of operation, the output of the module was 40 amperes, 95.3 ma/cm^2 and the total module voltage varied between 6.55 and 6.71 volts. The load was increased to 50 amperes, 119 ma/cm^2, for the next six hours with a total module voltage of from 6.20 to 6.27 volts. The module load was then decreased to 30 amperes, 71.5 ma/cm^2 for the last 25 hours of the test series with a total module voltage ranging from 6.07 to 6.60 volts.

The first 91.8 hours of operation are of special interest in connection with the cell performance tests. Figure 8 shows the total module voltage, load in amperes, average module temperature in ° C, and the water vapor pressure in both the hydrogen and oxygen gases as they entered the cells as a function of time. The vapor pressures are expressed as equivalent percent of KOH at corresponding average module temperatures. It will be noted that during this 91.8 hour period, at a constant load of 40 amperes and a constant module temperature of 93° C, the total module voltage showed a very gradual drop. During this same period, note the gradual decrease in equivalent % KOH concentration in both the hydrogen and oxygen gases. The decrease was necessary to maintain the module voltage at rated level.

The second module operated under load for 113-3/4 hours before the test series was terminated. The performance of this module was affected in essentially the same way as the previous module.

The third module applied the improved internal manifolding to a design which manifolds the reactants through one end plate to facilitate a canisterized construction. Poor nickel plating on four of the bi-polar plates caused the tests to be terminated after 40 hours of operation, however, the initial performance was good.

The four bi-polar plates have been cleaned and replated. The module will be rebuilt and tested early in April. In this module and all future modules, sealing will be accomplished with an unwaxed electrolyte vehicle and a compatible gasket.

4.0 BREADBOARD SYSTEM COMPONENT DEVELOPMENT

During this quarter a contract extension was received to develop the breadboard system. In testing to the present time, these components have been either simulated or eliminated from the system. In an actual breadboard system there would be two major subsystems - the gas recirculation system and the coolant system. Work has commenced in both areas during the period covered by this report.

4.1 Gas Recirculation System

The theory behind operation of the gas recirculation system is covered in the first quarterly report. Module tests have indicated that recirculation of the oxygen gas may be desirable. For this reason the initial breadboard design consists of a recirculation loop for each reactant gas. Figures 9 and 10 are schematic drawings of these systems. The major components which require development are the gas pumps and a means of separating the required amount of moisture from the gas.

4.1.1 Pumps

Several types of pumps were tested in order to determine the type best suited to a breadboard system. An ejector type pump was rejected after testing due to low efficiency. Although a diaphragm type pump showed some promise, a rotary vane type pump was finally selected for further testing because less development work appeared necessary to produce a model suitable for breadboard construction. As mentioned earlier, the improved internal manifolding made the axial fan another possibility.

4.1.1.1 Ejector Type Pumps

An investigation has been made to determine the feasibility of using an ejector type pump to circulate the reactant gases in a fuel cell recirculating system.

The test circuit illustrated in Figure 11 is of a plexiglas cylinder 61 cm long by 10.2 cm I.D., having an antivortex baffel above the water connection to the gear pump inlet port. The gear pump discharge port is connected to the 1.9 cm ejector, water inlet. Half the volume of the plexiglas cylinder was filled with water, the remainder of the system was pressurized with air to 1.68 atmospheres. Water entering the ejector at 3.71 atm was discharged from the ejector into the cylinder tangentially to produce a vortex around the gas discharge tube. The jet of water passing through the ejector produced a pressure drop in the gas circuit, thereby causing a gas flow from the cylinder through the heater and into the ejector. Hot moist gas was mixed with the cool water in the ejector, thereby condensing moisture in the gas. Saturated gas was separated from the water by the vortex action within the 10.2 cm I.D. cylinder. Water forced through the ejector at the rate of 9.66 liters per minute and 3.7 atm inlet pressure, circulated only 14 liters/minute of air through the gas circuit. The test was discontinued due to the low efficiency of the system.

4.1.1.2 Diaphragm Type Pump

Several tests were run on a diaphragm type pump of the general type illustrated in Figure 12. Since a model suitable for pumping hydrogen was not available, a commercial air pump was used for the initial tests.

The tests showed the pump was feasible for the purpose. However, considerable development work would be necessary to reduce size and weight, improve efficiency and increase reliability of the valves and diaphragm.

The principle advantage of this type pump is that sealing the rotating shaft is unnecessary, a particular advantage when pumping hydrogen. It is a positive displacement pump, potentially having adequate capacity, efficiency and reliability.

4.1.1.3 Rotary Vane Type Pump

Several commercially available positive displacement vane type pumps as shown in Figure 13 were purchased and tested. The pump interiors were plated with nickel and the bore was chrome plated and ground. These pumps appear to be more readily adaptable to breadboard construction in that less development would be necessary to produce a pump suitable for breadboard use. Shaft seals and vanes are the principle trouble areas.

(1) Vane Material

The standard graphite vanes in the H_2 recirculating system pump have operated satisfactorily from February 7 to March 21, at which time two vanes broke. This failure was probably caused by too much condensed H_2O in the system during a test of the separator, although there was no injurious effect at a previous time when an H_2O manometer was inadvertently emptied into the H_2 gas system.

Testing of Dupont Type A Polymer SP-1 material referred to in Monthly Progress Report No. 10 was continued for a total time of 400 hours. Each vane machined from this material weighed 9.75 grams as machined. The weight per vane after 112 hours of operation, circulating dry hydrogen at 93° C, was 9.5 grams. Inspection of wear marking at this time showed vane wear pattern to be similar to wear pattern observed on graphite vanes operating under similar conditions. However, the pump, Model 1, cylinder bore, had a burnished appearance and very slight grooves around the circumference of the cylinder.

The vanes were placed in a Model 2 pump having a smooth ground chrome bore, polished by running for a considerable time with graphite vanes. The Model 2 pump operated with SP-1 vanes for 288 hours pumping dry H_2, H_2 with vapor, air at atmospheric pressure and air with H_2O vapor. Differential pressure between inlet and outlet ranged from atmospheric to 18.7 mm Hg with gas temperatures ranging from room temperature to 104° C. Each vane was found to weigh 8.5 grams after 400 hours total operating time. The vane thickness had been reduced approximately 15% over areas in contact with rotor slots. The inside surface of the pump cylinder again had a burnished appearance and was slightly grooved. A vane material having wear qualities superior to graphite has not yet been obtained.

(2) Shaft Seals

Mechanical shaft seals made of carbon appear to be doing an adequate job of preventing hydrogen leakage around shaft of the hydrogen rotary vane pump.

(3) Bearings and Lubricants

Ball bearings used in the vane type pumps of the gas recirculation systems should be of the double-shielded, grease-packed type. The grease furnished with these bearings must be a type which will not oxidize in the event shaft seal leakage from the oxygen recirculating system occurs. Oxidation bomb tests on grease lubricants at 99° C using pure oxygen under 7.5 atmospheres have been conducted for periods of time in excess of 500 hours by bearing manufacturers. These tests have demonstrated the following greases are satisfactory for lubrication of ball bearings running in an oxygen atmosphere:

Cosmolube	615
Andok	C
Chevron	OHT

Ball bearing shields are commonly made of Buna-N rubber which will deteriorate rapidly in an oxygen atmosphere. Bearing shields made of Viton are considerably more resistant to oxygen and should be furnished with bearings used in the recirculating system.

4.1.1.4 Axial Fan

In view of the greatly reduced pressure drop through the cell as a result of the internal manifolding modification mentioned above, a positive displacement pump may not be necessary. If suitable, an axial fan of the type illustrated in Figure 14 would be desirable from several standpoints. Power requirements, size and weight would be reduced, reliability increased and sealing problems practically eliminated.

A Roton fan with the following rating has been obtained for test:

Model AXIMAX 3	
Motor 528 YS	RPM 22000
Volts - 115	Temp. Max. - 125° C
Amps - 1.3	Disch. O Press. - 4,590 liters/min
cps - 400	Cap. Mfd. - 2.0
Phase I	Press. shut off - 7.85 mm Hg

Preliminary test data is summarized in Figure 15.

All tests were made with air at atmospheric suction pressure. The fan drive motor is normally cooled by the gas flowing through the system, therefore, a time-temperature rise test was made with a thermocouple against the motor housing and suction port closed. Obviously means must be provided to cool the motor in the event recirculated gas entering the fan from the condenser-separator at 76° C is of insufficient rate to maintain motor temperature below rated temperature rise of 125° C.

The fan will be set up in a closed H_2 circulating system for additional testing.

It is expected that the fan motor size, could be reduced and the weight and efficiency could be increased if three phase power was used.

4.1.2 Gas-Water Separators

One of the basic components necessary in the gas recirculation system is a means for separating condensed water from the gas. The following is a summary of the work done on several different types of gas-water separators.

A spiral and a conical separator which depended on centrifugal force for separation were tested and rejected because of the additional parasitic power to attain the necessary entrance velocity.

A combination condenser-separator has been developed which will be used on the breadboard system.

4.1.2.1 Spiral Separators

Figures 16 and 17 show the first separator design tested. A mixture of gas and water droplets entered the cylinder tangentially at a high velocity. The water droplets were held against the perimeter of the cylinder by centrifugal force. This force, a function of the entrance velocity of the fluid, must be sufficient to hold the droplets against the cylinder wall regardless of the gravitational forces. The spiral was provided to positively direct the path of the droplets toward the water outlet. Saturated gas, separated from the water droplets, is exhausted from the separator through a tube located in the center of the cylinder. Although no provision was made to prevent gas from escaping from the separator through the water exit except by a water seal, the device did separate water droplets from the gas stream effectively when a sufficient entrance velocity of the mixture was maintained.

4.1.2.2 Conical Separators

Figure 18 shows a second gas-water separator similar in operating principle to the spiral-type separator described above. Under test the saturated gas and condensed water mixture entered at the base of the two cones at high velocity. The droplets of condensate clung to the surface of the cone and traveled toward the apexes in long spiral paths. The saturated gas was discharged from the separator through a tube located near the center of the conical chamber.

4.1.2.3 Condenser-Separators

The tests conducted on both the spiral and conical separators indicated that they would work under zero gravity conditions when the entrance velocity of the gas-water mixture was high enough. However, the additional parasitic power required from the fuel cell to attain this velocity was a disadvantage. To eliminate the need for this additional power requirement, a combination condenser-separator was designed, as illustrated in Figure 19.

In this model the gas-water vapor mixture passes through a water cooled tube bundle where the moisture is condensed. The gas and condensed vapor is then passed over an asbestos diaphragm which absorbs the moisture. The pressure differential across the diaphragm then, in effect, pumps the moisture into a collection container. The device operated satisfactorily in either the position shown or inverted.

Another model similar to this was constructed as shown in Figures 20 and 21. A large number of 157 mm I.D., 0.2 mm wall thickness stainless steel tubes were used to reduce pressure drop and insure movement of the condensed moisture toward the asbestos under zero gravity conditions. Initial tests showed satisfactory performance.

Testing of the above separators was discontinued when an improved version was constructed as shown in Figure 22.

The gas vapor mixture from the fuel cell entered each end of the unit flowing toward the center exit port. Equally spaced ribs between the asbestos-separator and cover containing the gas ports formed guide channels for the gas. A perforated plate located on the opposite side of the asbestos separator provides an exit for the condensate together with a firm support for the separator material.

Another plate, the heat transfer plate, spaced 8 mm from the perforated plate and containing two condensate discharge tubes, provided a means of removing the condensate through the coolant flow channel. The heat transfer plate and the condenser body formed the channel for coolant flow. Coolant fluid circulated through a center inlet port, over the heat transfer plate and was exhausted out each end of the assembly. Gas and water vapor mixture flowing into the ends of the unit, over the cooled separator surface toward the center exit, cooled the vapor which condensed on the separator surface and was absorbed into the asbestos separator.

Heat transfer to the gas side of the separator was not satisfactory, therefore, the separator elements were rearranged as indicated in Figures 23 and 24.

Figure 23 shows the separator-condenser altered so that the gas channel and coolant flow passage are separated by the thin aluminum heat transfer plate. The opposite side of the gas channel was formed by the separator surface. Appropriately spaced ribs on each side of the transfer plate formed guide channels, directing the flow of the two fluids. Water vapor condensed in the gas passage, came in contact with the separator surface, was absorbed into the separator, and passed out of the system through condensate drain tubes.

These tests indicate a condenser-separator of this type will perform satisfactorily in a gas recirculating system designed for a 1 KW fuel cell. Additional testing will be required to determine if the design is satisfactory for service in variable gravity fields.

4.2 Cooling System

To utilize Vapor Pressure Control with a recirculated gas system, it is important to maintain the temperature relationship of the fuel cell and condensers within predetermined limits. These temperatures will be maintained by mixing valves located in the coolant lines. A schematic of the fuel cell cooling system is shown in Figure 25.

The coolant will leave the fuel cell at approximately 93° C and is circulated through a radiator by a motor driven pump. The cooled liquid then flows through the condensers and back into the fuel cell. A mixing valve located at the condenser coolant inlet will control the temperature of the saturated reactant leaving the condenser by automatically by-passing a portion of the hot liquid around the radiator. A similar mixing valve, located between the condenser coolant outlet and fuel cell coolant inlet port will maintain the proper cell temperature. This valve will be adjusted to a higher discharge temperature than is the mixing valve located in the condenser coolant line.

4.2.1 Mixing Valves

Three commercial mixing valves have been tested to determine pressure drops across the valves at various flow rates and temperature settings and to determine the reference temperature tolerance at various coolant flow rates.

All the valves tested incorporated an internal temperature sensor. A modification, Figure 26, in the valve design is being made so that the reference temperature controlling the condenser mixing valves can be located in the reactant gas line.

4.2.2 Coolant Circulating Pumps

The original laboratory cooling system was equipped with a centrifugal pump. This pump became vapor bound at times, causing partial to complete reduction in flow of cooling liquid through the condenser. The flow was also rather sensitive to pressure changes within the closed system. Various types of bleeder connections were used to eliminate accumulation of vapor within the pump, however, the centrifugal pump did not possess the reliability required, therefore, this pump was replaced with a positive displacement gear pump, which has eliminated the vapor problem.

5.0 CONCLUSIONS

Initial evaluations of the gas chromatograph and the eight-cell module tests have produced experimental evidence to support the theory of fuel cell operation with Vapor Pressure Control.

Cell performance tests have shown that the KOH was gradually reacting with the wax used for sealing causing a change in control characteristics over an extended period of time. This has led to improved sealing techniques eliminating the wax.

The results of the breadboard system component testing and development have produced a static gas-water separator which appears suitable for zero gravity conditions. The use of rotary vane pumps for gas recirculation and a gear type pump for coolant recirculation have been selected for the initial breadboard system.

6.0 FUTURE WORK

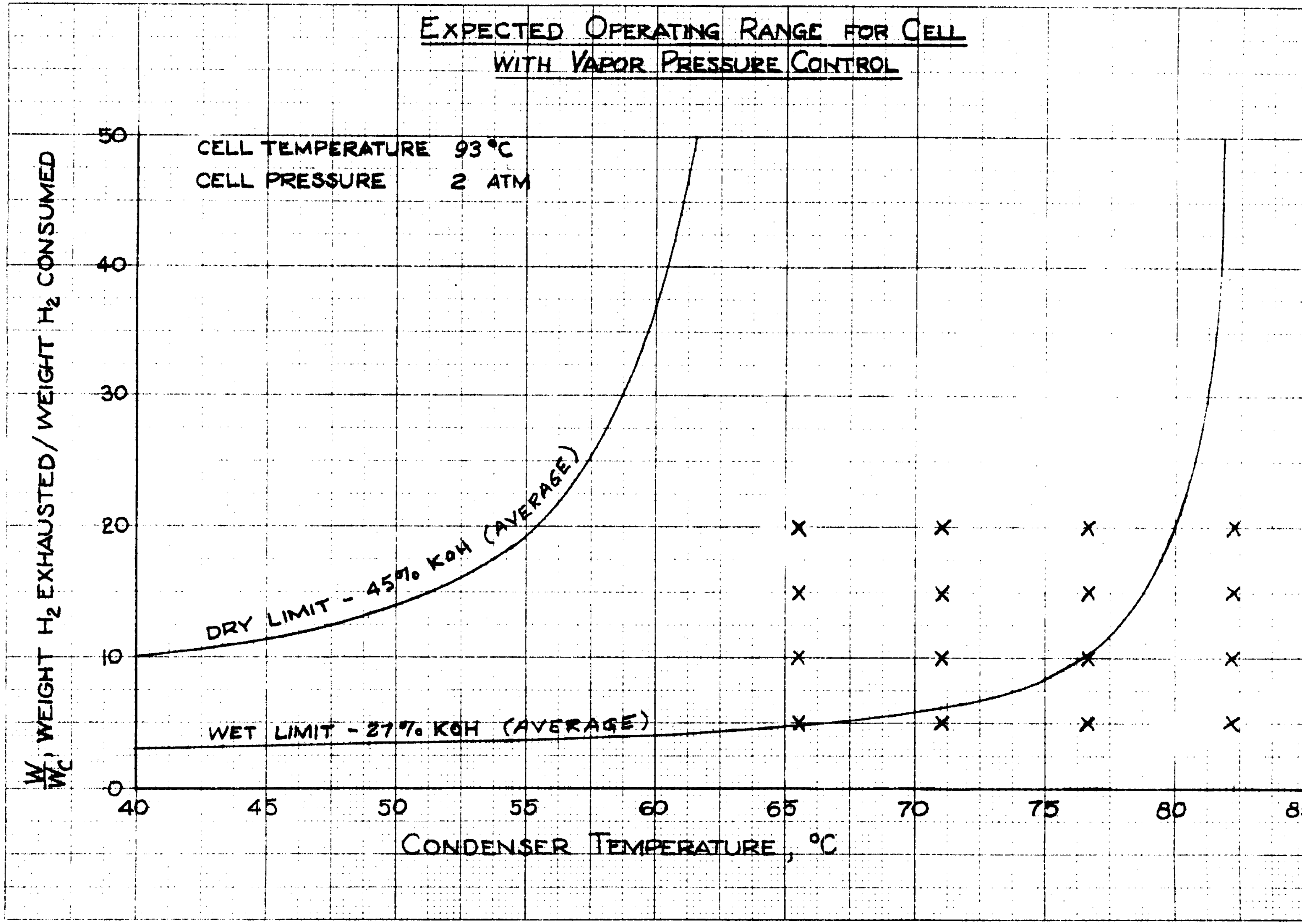
During the next quarter, the following programs are planned:

1. Complete gas chromatograph testing and evaluation.

2. Construct and operate initial breadboard system.

3. Initiate an extended test on an eight-cell module.

4. Continue development and refinement of breadboard system components.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WITH VAPOR PRESSURE CONTROL
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CELL PRESSURE 2 ATM
DRY LIMIT - 45% KOH (AVERAGE)
WET LIMIT - 27% KOH (AVERAGE)
W/Wc, WEIGHT H2 EXHAUSTED/ WEIGHT H2 CONSUMED
CONDENSER TEMPERATURE, °C
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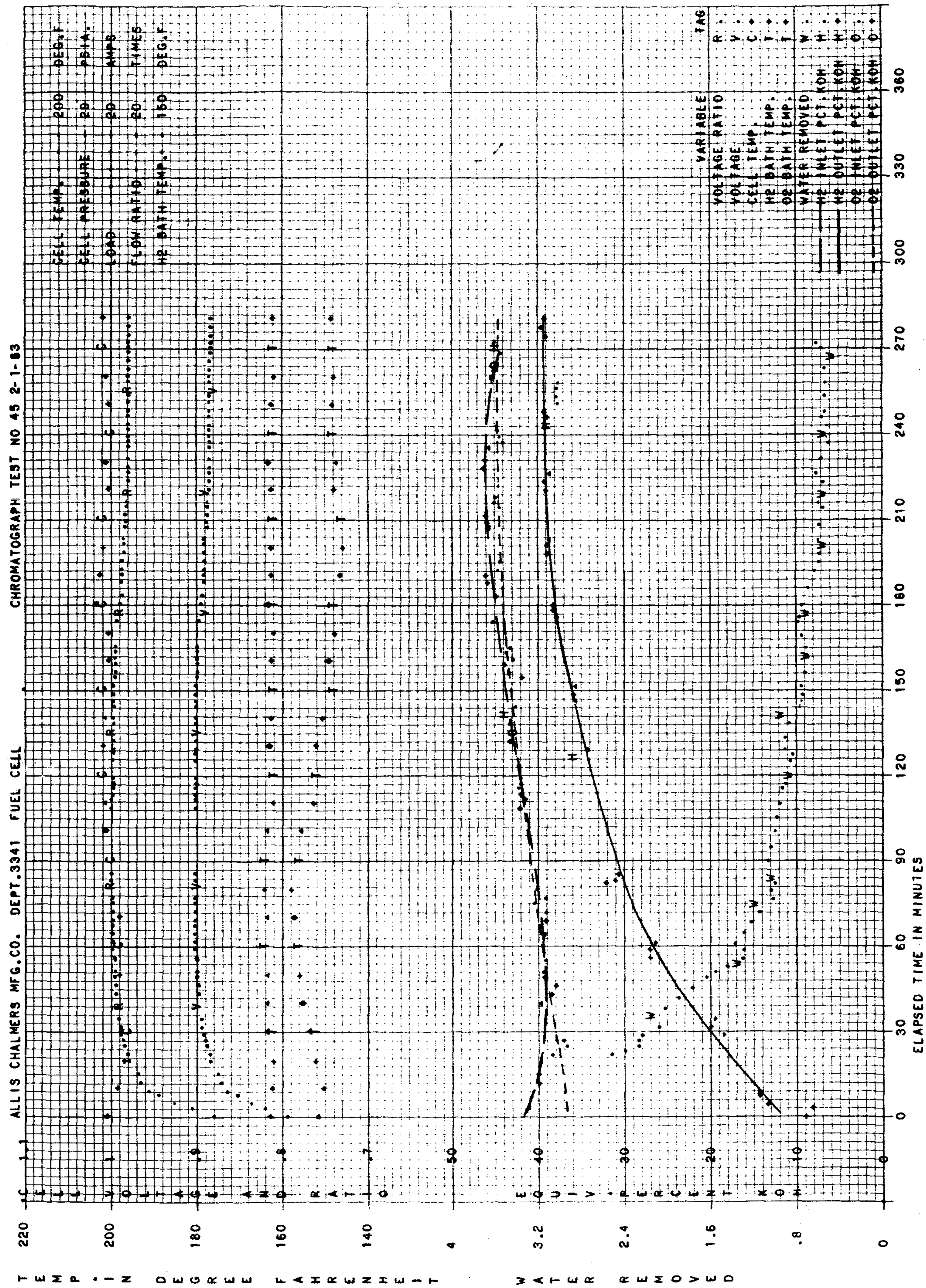
40
50
40
45
50
55
60
65
70
75
80
85

FIG. 1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VOLTAGE V
CELL TEMP. C
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O2 BATH TEMP. I
WATER REMOVED W
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H2 OUTLET PCT.KOH H
O2 INLET PCT.KOH O
O2 OUTLET PCT.KOH O
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EQUIV. PERCENT KOH

Figure 2

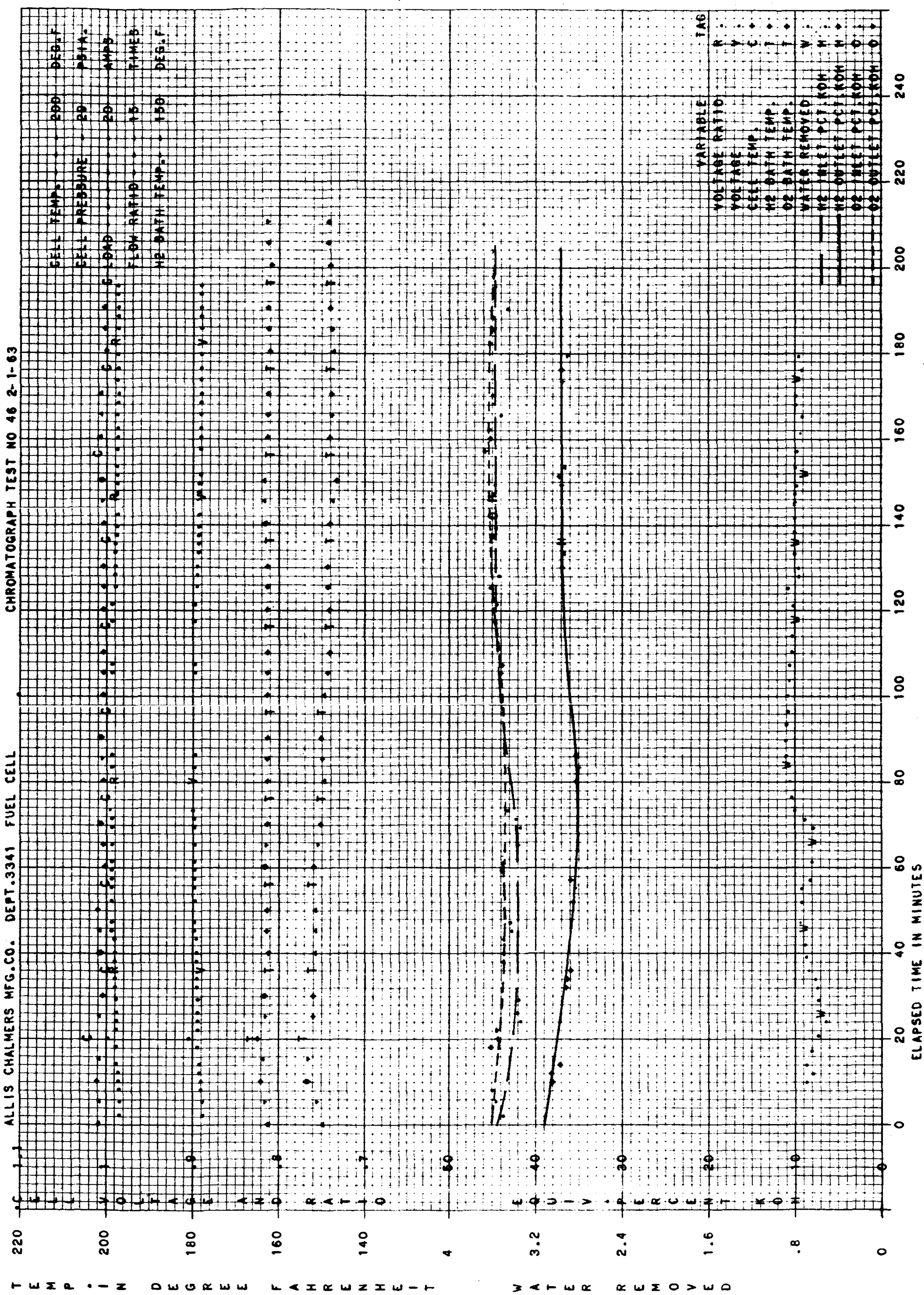
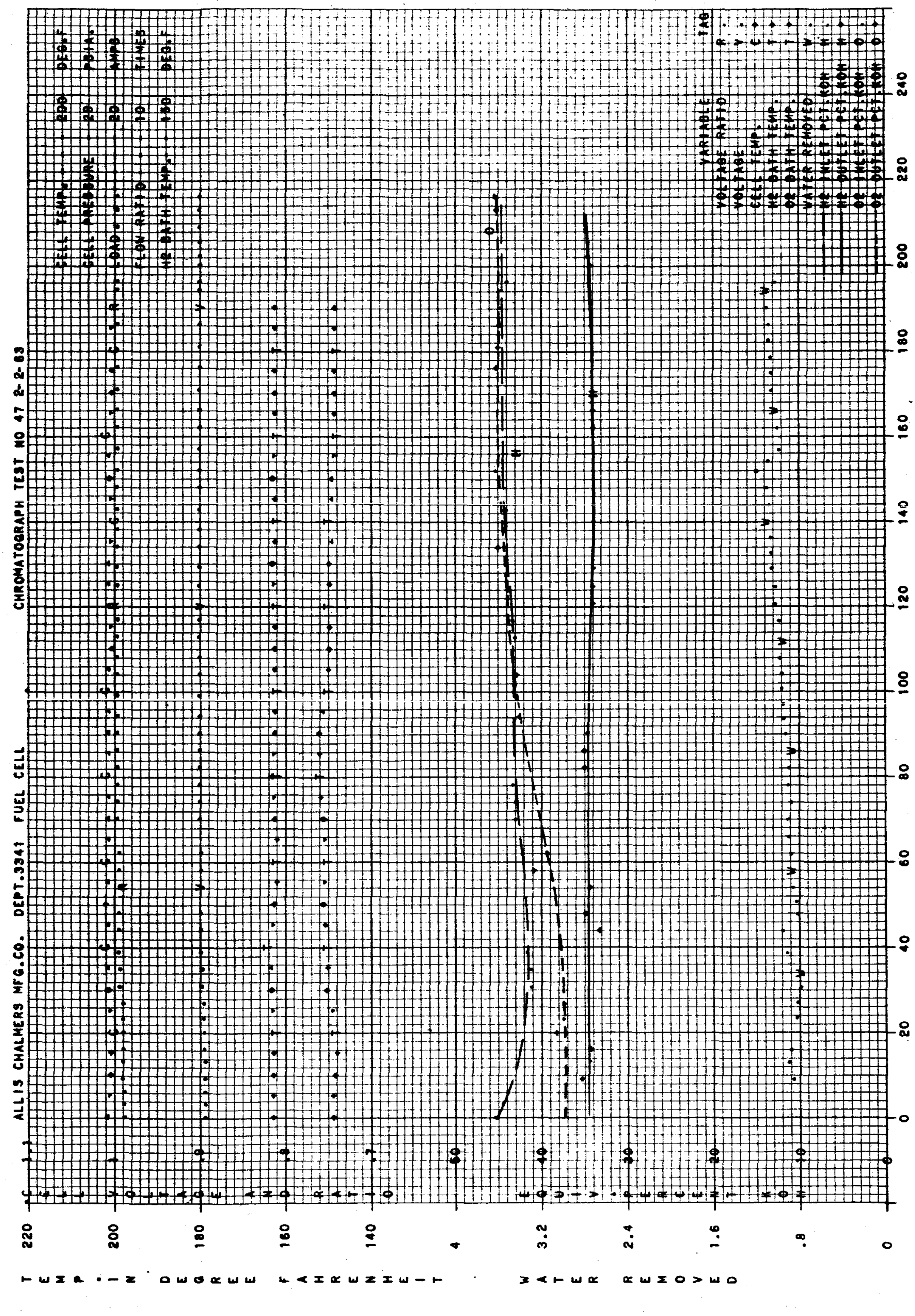
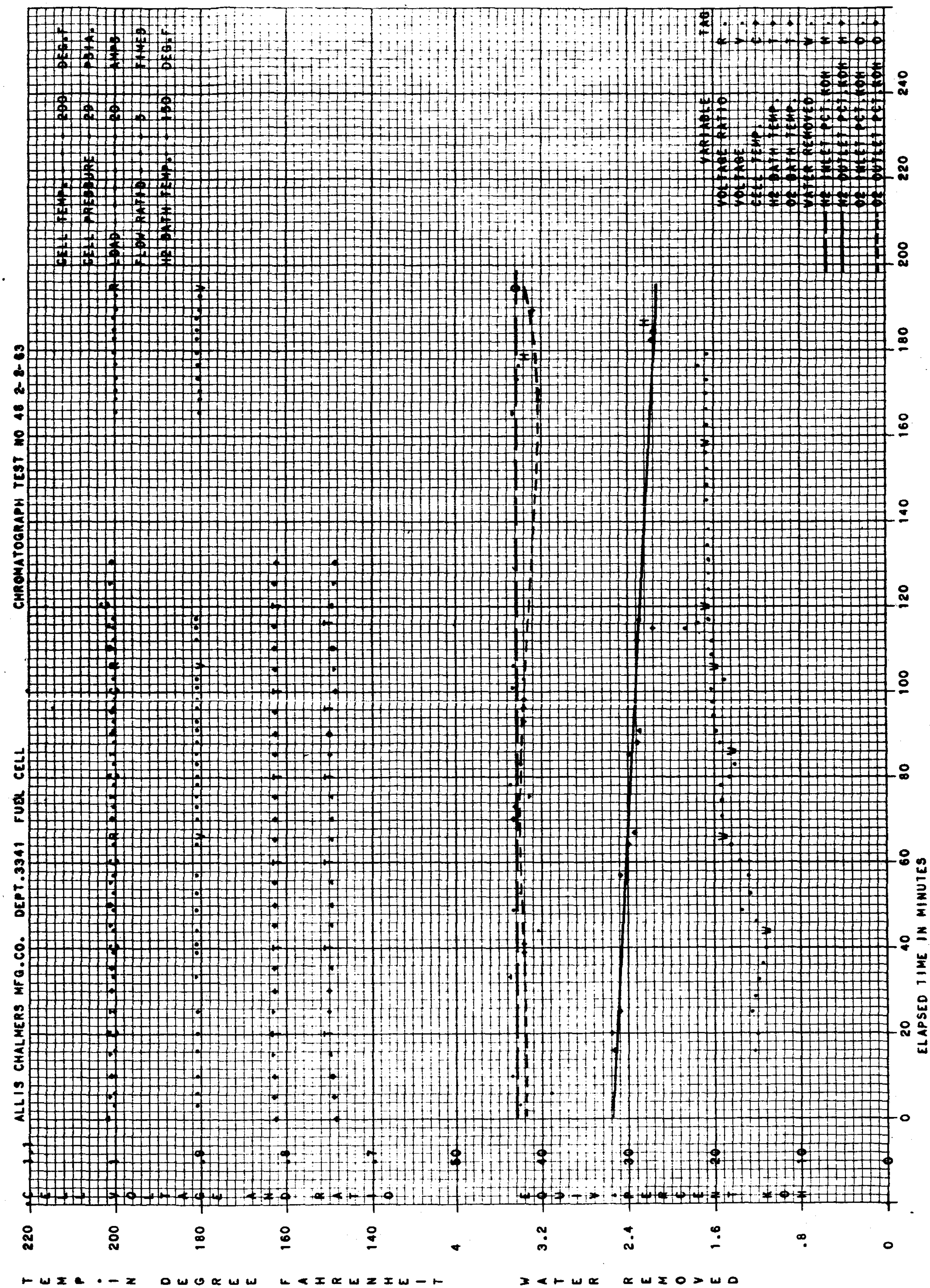

ALLIS CHALMERS MFG.CO. DEPT.3341 FUEL CELL
CHROMATOGRAPH TEST NO 46 2-1-63
CELL TEMP. 200 DEG.F
CELL PRESSURE 29 PSIA.
CELL LOAD 20 AMPS
FLOW RATIO 1.5 TIMES
H2 BATH TEMP. 150 DEG.F
VARIABLE TAG
VOLTAGE RATIO R
VOLTAGE V
CELL TEMP. C
H2 BATH TEMP. T
O2 BATH TEMP. T
WATER REMOVED W
H2 INLET PCT.KOH H
H2 OUTLET PCT.KOH H
O2 INLET PCT.KOH O
O2 OUTLET PCT.KOH O
TEMP. IN DEGREE FAHRENHEIT
VOLTAGE AND RATIO
WATER REMOVED
EQUIV. PERCENT KOH
ELAPSED TIME IN MINUTES
220
200
180
160
140
4
3.2
2.4
1.6
.8
0
0
20
40
60
80
100
120
140
160
180
200
220
240

Figure 3



ALLIS CHALMERS MFG.CO. DEPT.3341 FUEL CELL CHROMATOGRAPH TEST NO 47 2-2-63
CELL TEMP. 200 DEG.F
CELL PRESSURE 20 PSIA.
LOAD 20 AMPS
FLOW RATIO 10 TIMES
H2 BATH TEMP. 150 DEG.F
VARIABLE TAG
VOLTAGE RATIO R
VOLTAGE V
CELL TEMP. C
H2 BATH TEMP. T
O2 BATH TEMP. T
WATER REMOVED W
H2 INLET PCT.KOH H
H2 OUTLET PCT.KOH H
O2 INLET PCT.KOH O
O2 OUTLET PCT.KOH O
ELAPSED TIME IN MINUTES
TEMP IN DEGREE FAHRENHEIT
WATER REMOVED
CELL VOLTAGE AND RATIO
EQUIV. PERCENT KOH

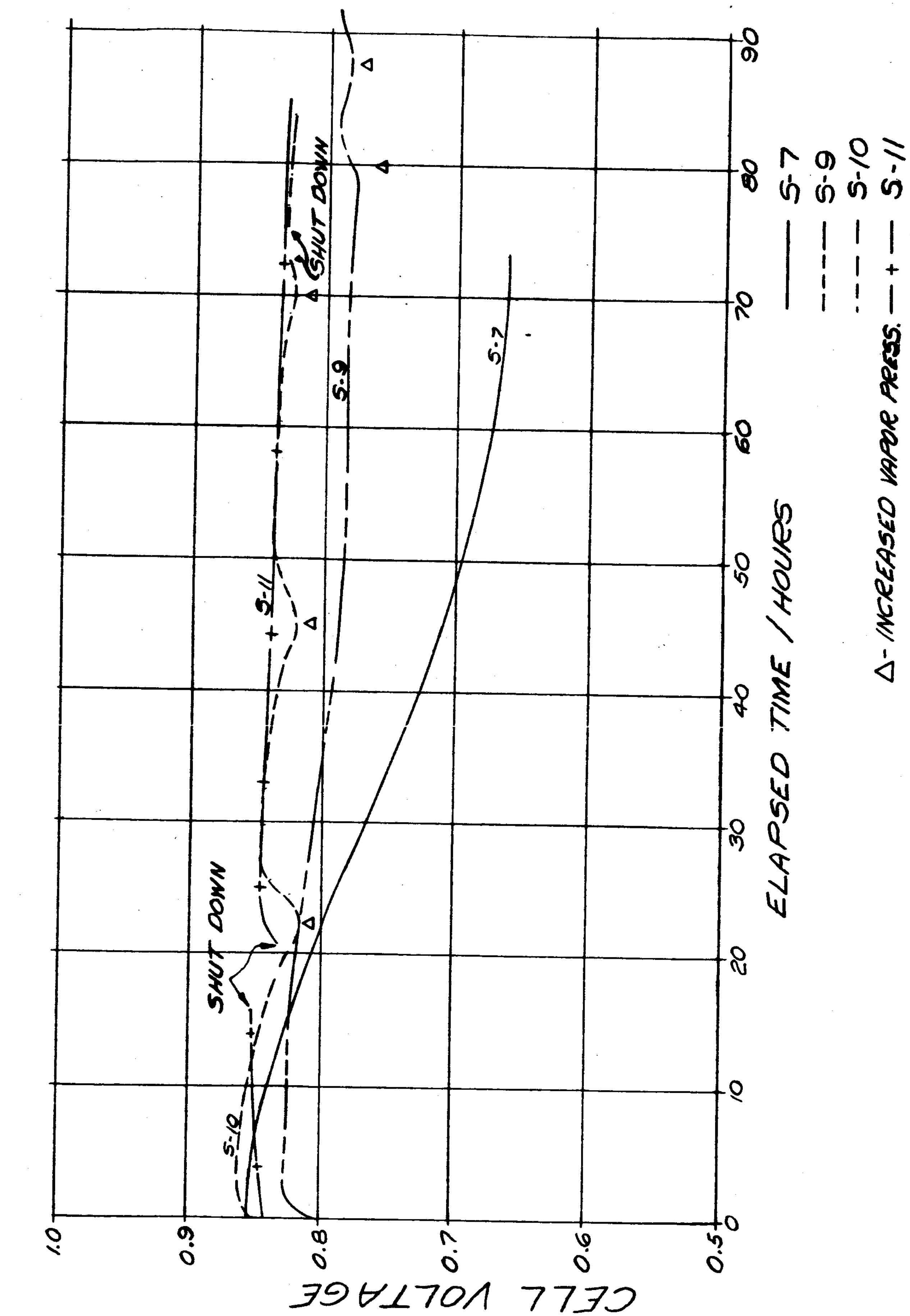
Figure 4



ALLIS CHALMERS MFG.CO. DEPT.3341 FUEL CELL
CHROMATOGRAPH TEST NO 48 2-8-63
CELL TEMP. 200 DEG.F
CELL PRESSURE 29 PSIA.
LOAD 20 AMPS
FLOW RATIO 5 TIMES
H2 BATH TEMP. 150 DEG.F
VARIABLE TAG
VOLTAGE RATIO R
VOLTAGE V
CELL TEMP. C
H2 BATH TEMP. T
O2 BATH TEMP. T
WATER REMOVED W
H2 INLET PCT.KOH H
H2 OUTLET PCT.KOH H
O2 INLET PCT.KOH O
O2 OUTLET PCT.KOH O
ELAPSED TIME IN MINUTES
TEMP. IN DEGREE FAHRENHEIT
WATER REMOVED
CELL VOLTAGE AND RATIO
EQUIV. PERCENT KOH

Figure 5

CELL PERFORMANCE TEST RESULTS



S.A.D.S.
ALLIS-CHALMERS MFG. CO.

FIG. 6

1-SK-63109-5

4-8-63
J.W.H.

CELL PERFORMANCE TESTS

EXHAUST WATER ANALYSIS

Test S-7

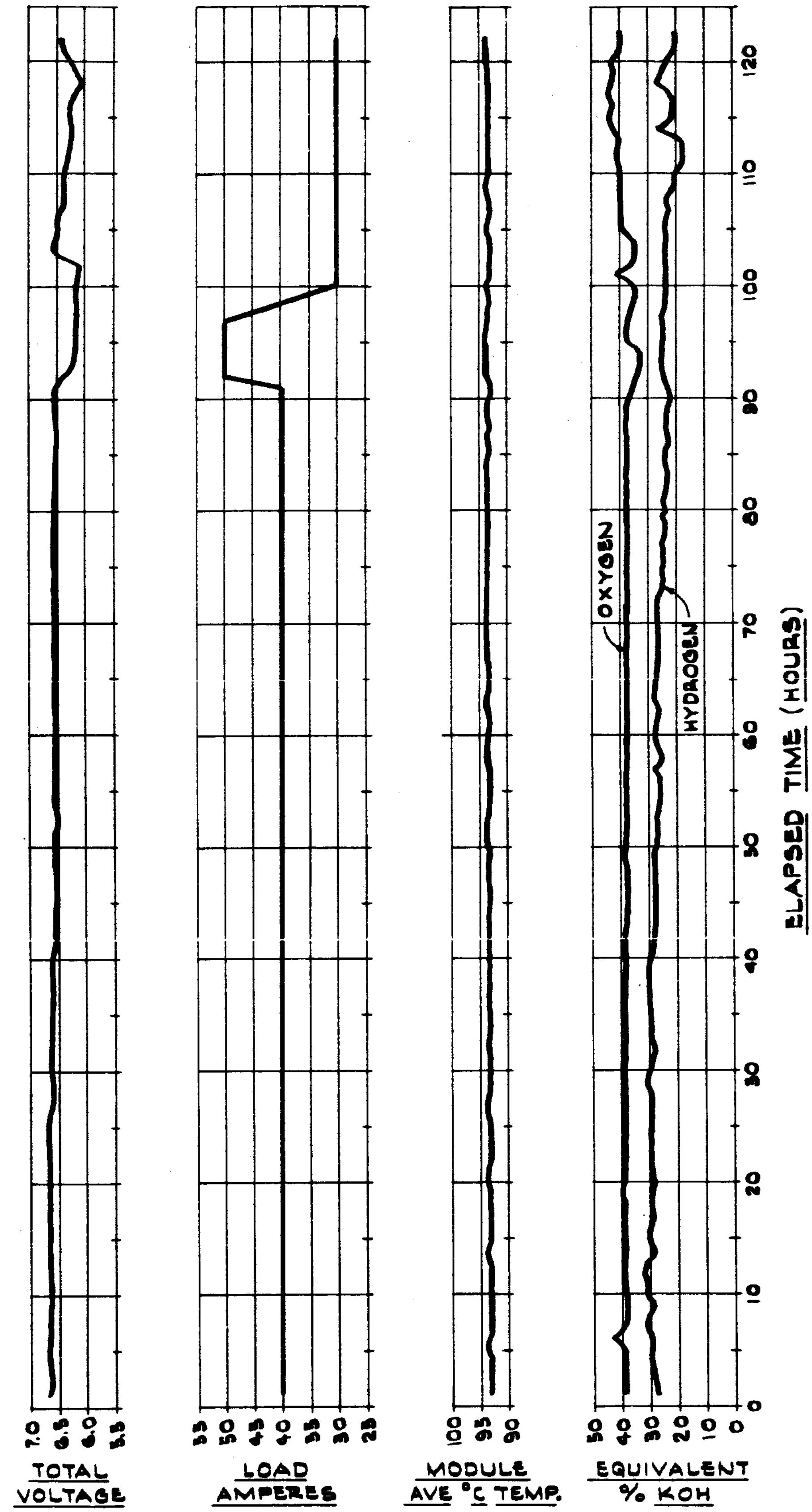
KOH	None Detected
Pt	None Detected
Pd	None Detected
KCO_3	.89 gm/l

Test S-9

Pd	None Detected
Pt	None Detected
KOH	None Detected
Carbonates	None Detected
Quantity	3,690 ml

Figure 7

EIGHT CELL MODULE TEST (MODIFIED INTERNAL MANIFOLDING)
DYNAMIC VAPOR PRESSURE CONTROL
CELL PRESSURE = 2 ATMOS.

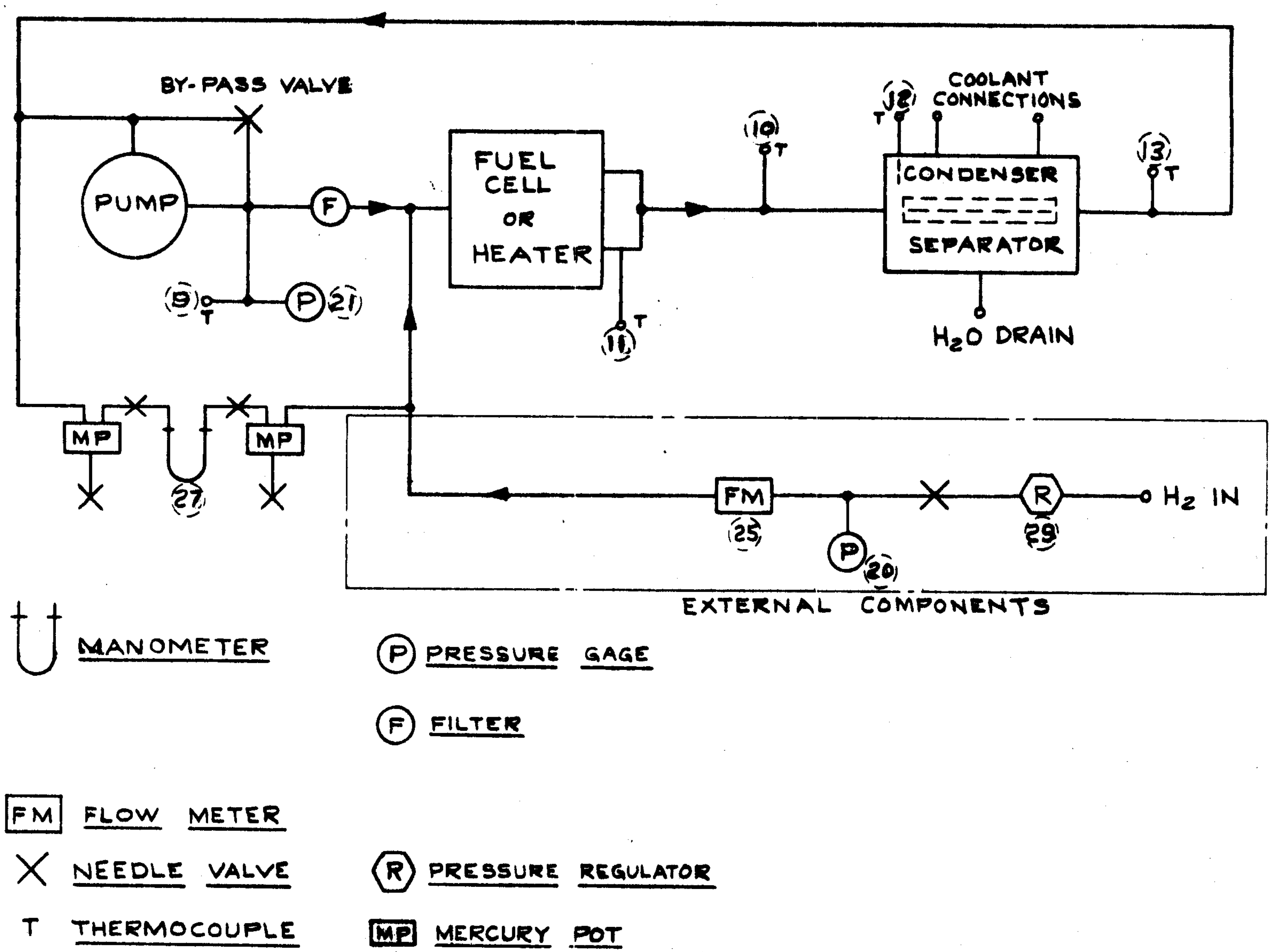


FIRST 1.3 HRS. USED TO STABILIZE MODULE AND CHECK VARIOUS LOAD LEVELS

S.A.D.S. - RESEARCH
ALLIS-CHALMERS MFG. CO.

FIG. 8

2SK63092-3
4-2-63 PLB



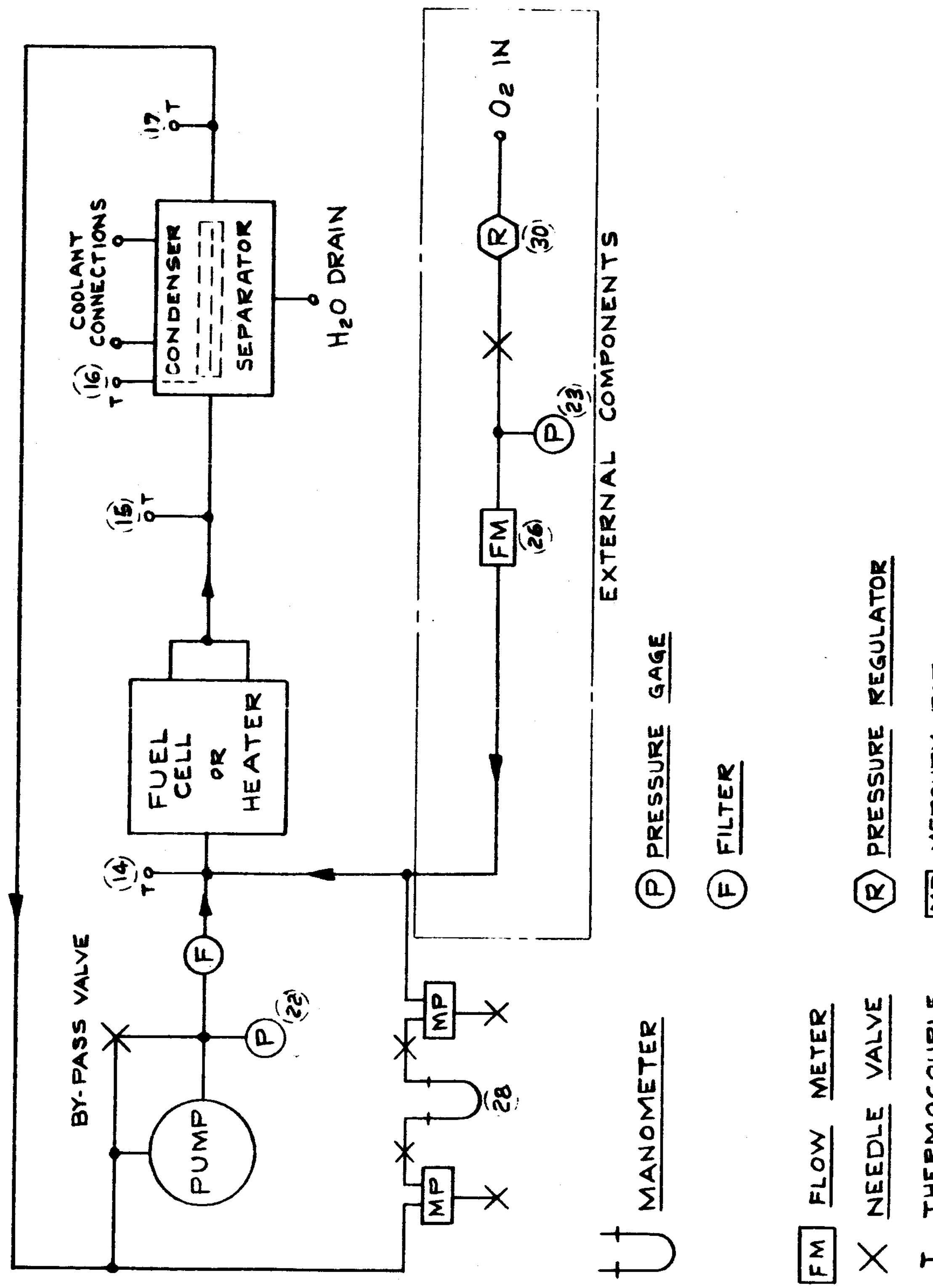
SCHEMATIC OF FUEL CELL H_2 SYSTEM

ALLIS-CHALMERS MFG. CO.

FIG. 9

1-SK-63067-1

REV. #2- 4-1963
REV. #1, 3-27-63
W.F.B. 3-11-63



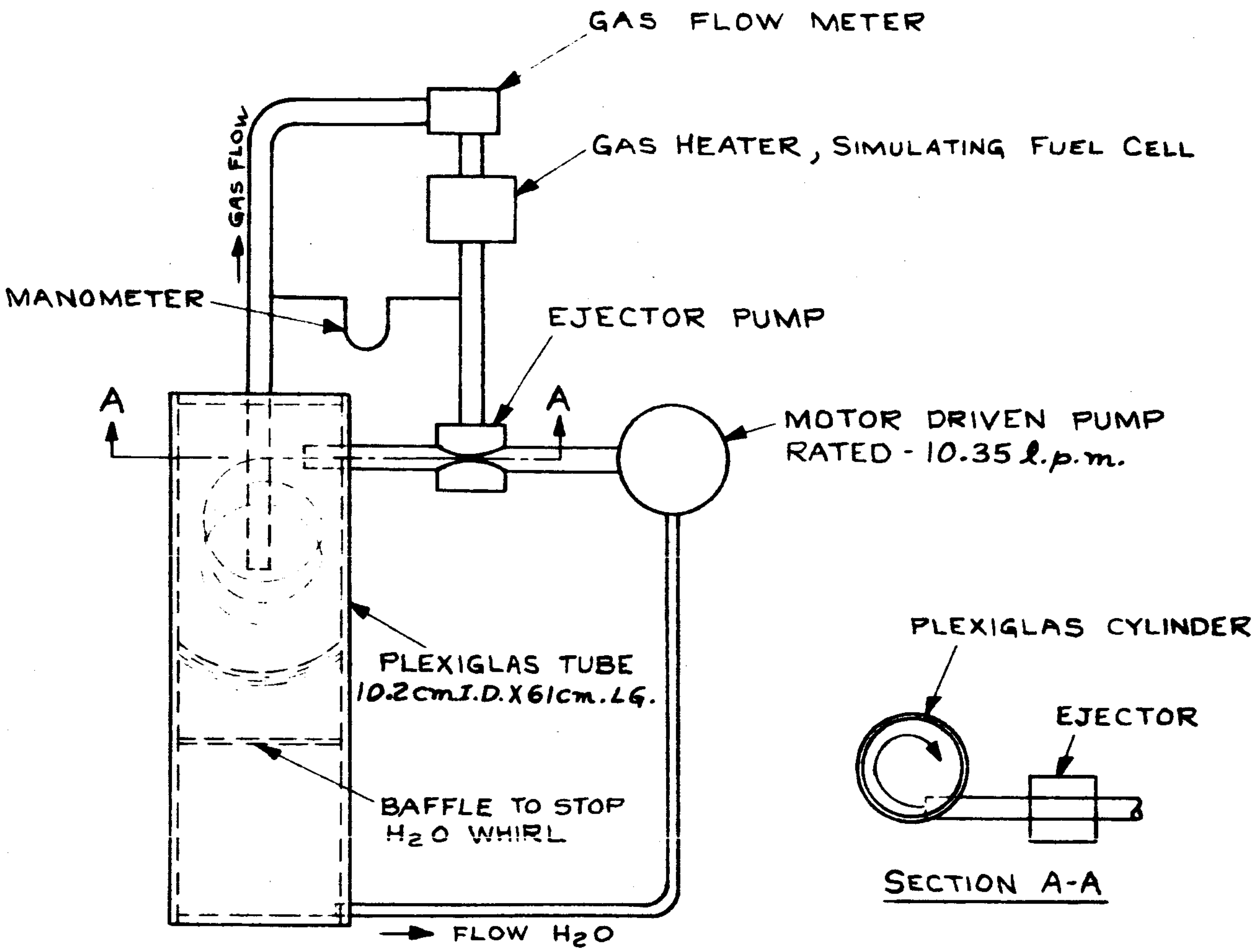
SCHEMATIC OF FUEL CELL O_2 SYSTEM

ALLIS-CHALMERS MFG. CO.

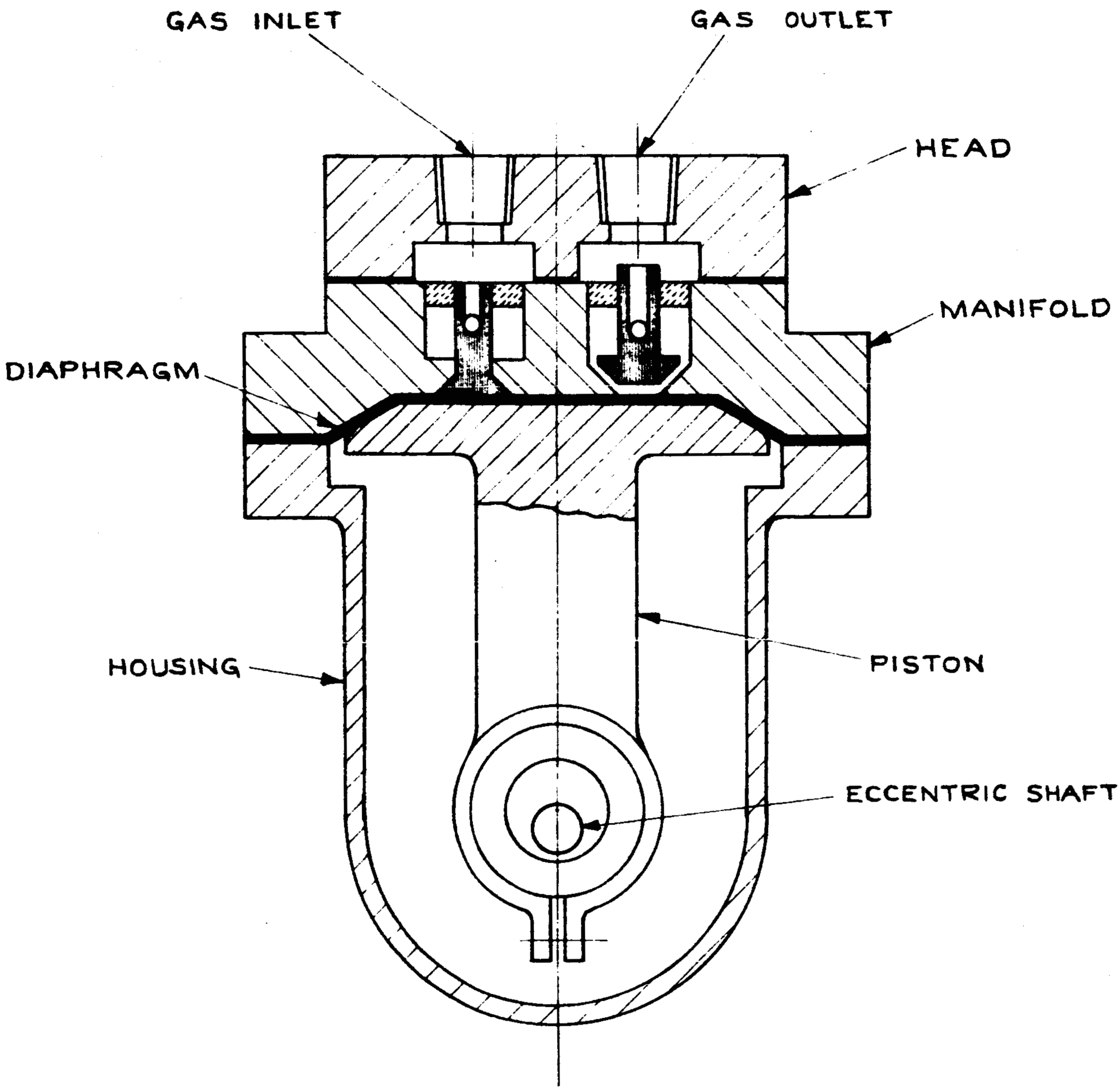
FIG. 10

1-SK-63067-1

REV. #2 - 4-19-63
REV. #1, 3-15-63
W.P.B 3-11-63



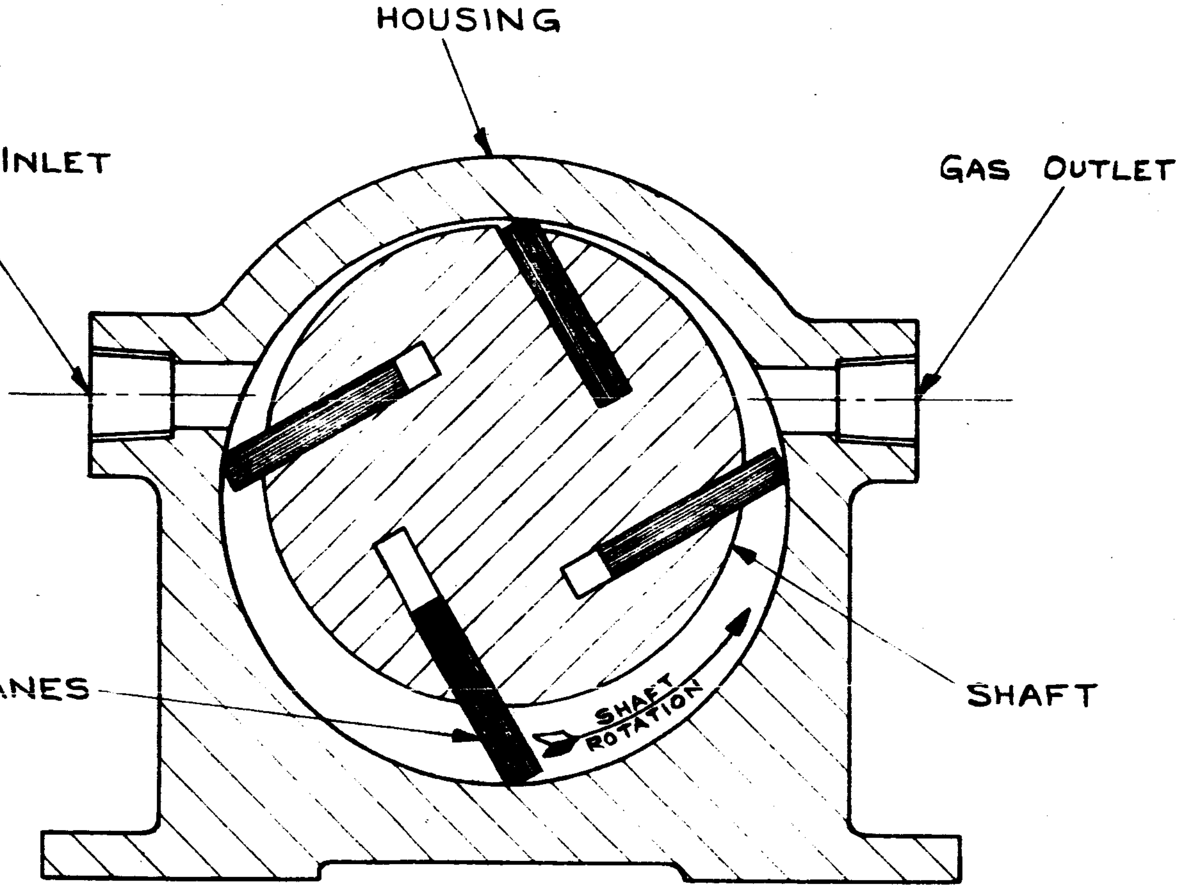
SCHEMATIC DIAGRAM
EJECTOR TYPE GAS PUMP



SECTION THROUGH GAS PUMP
DIAPHRAGM TYPE

1-SK-63087-19
1-29-63 N.P.B.

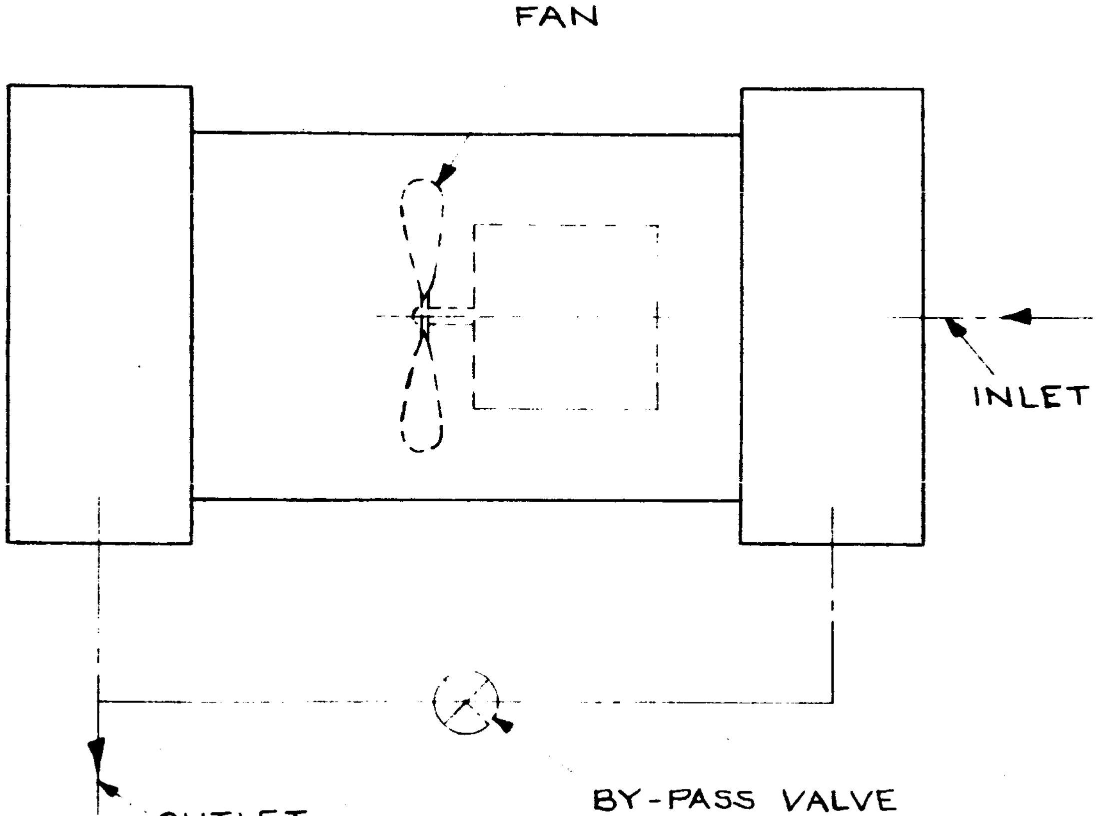
ALLIS-CHALMERS MFG. CO. FIG. 12



SECTION THROUGH GAS PUMP
VANE TYPE PUMP

ALLIS-CHALMERS MFG. CO. FIG. 13 1-SK-63087-18 1-28-63 Y.R.B.

ROTON FAN, MOTOR 528 YS
MODEL AXIMAX 3
V - 115 AMP. - 1.3
Cps - 400
PH. - 1
RPM - 22000
T. MAX. - 125 °C.
CAP. Mfd. - 2.0

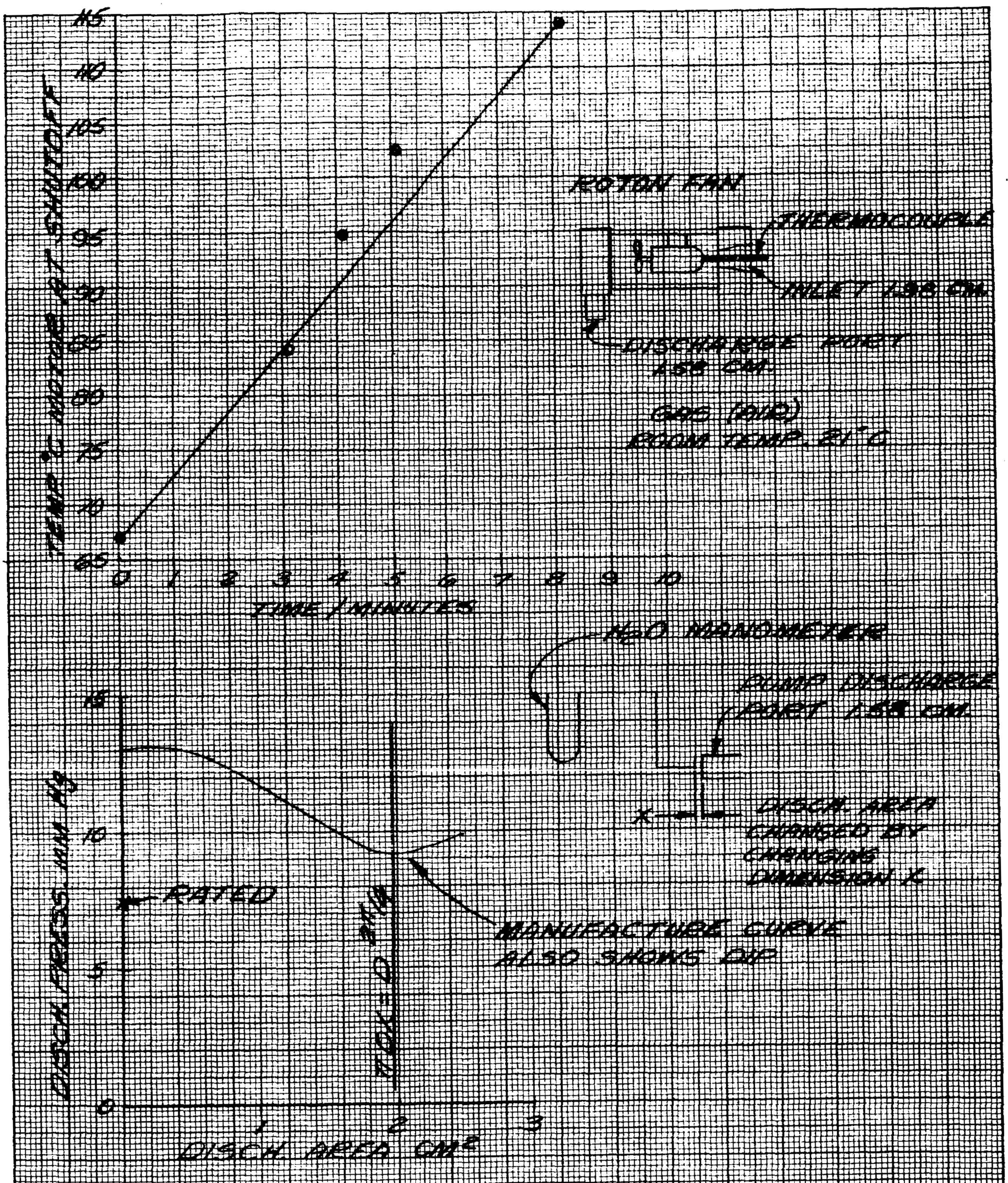


AXIAL TYPE FAN

ALLIS-CHALMERS MFG. CO.

FIG. 14

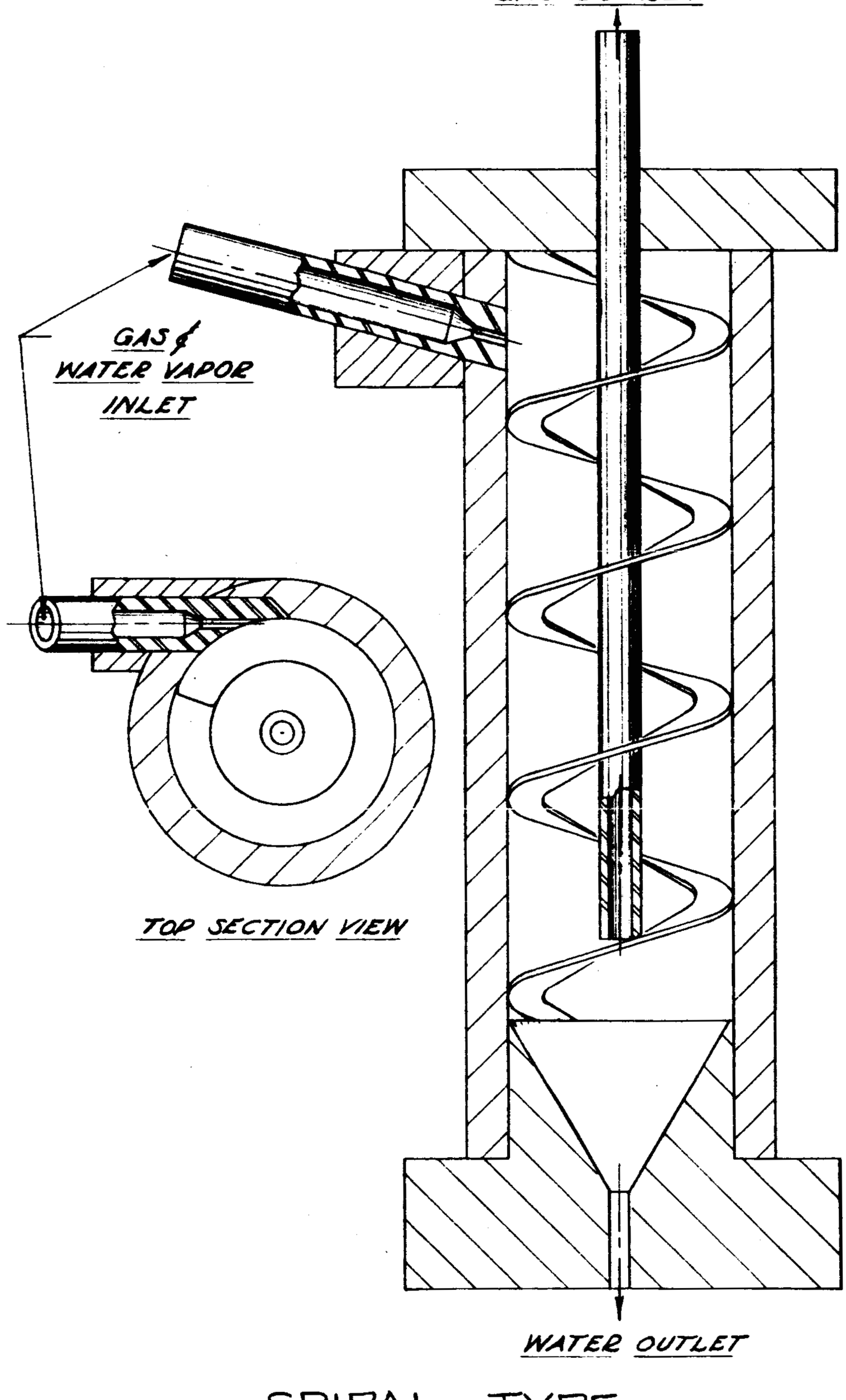
3-27-63 W.P.B.
1-SK-63087-20



TEST: ROTON FAN
RATED 4590 LITERS/MIN. 285 MM Hg SHUTOFF
MOTOR 528 YS
115 VOLTS 136 WATT WITH
1.3 AMPS. 2 MFD. CAP

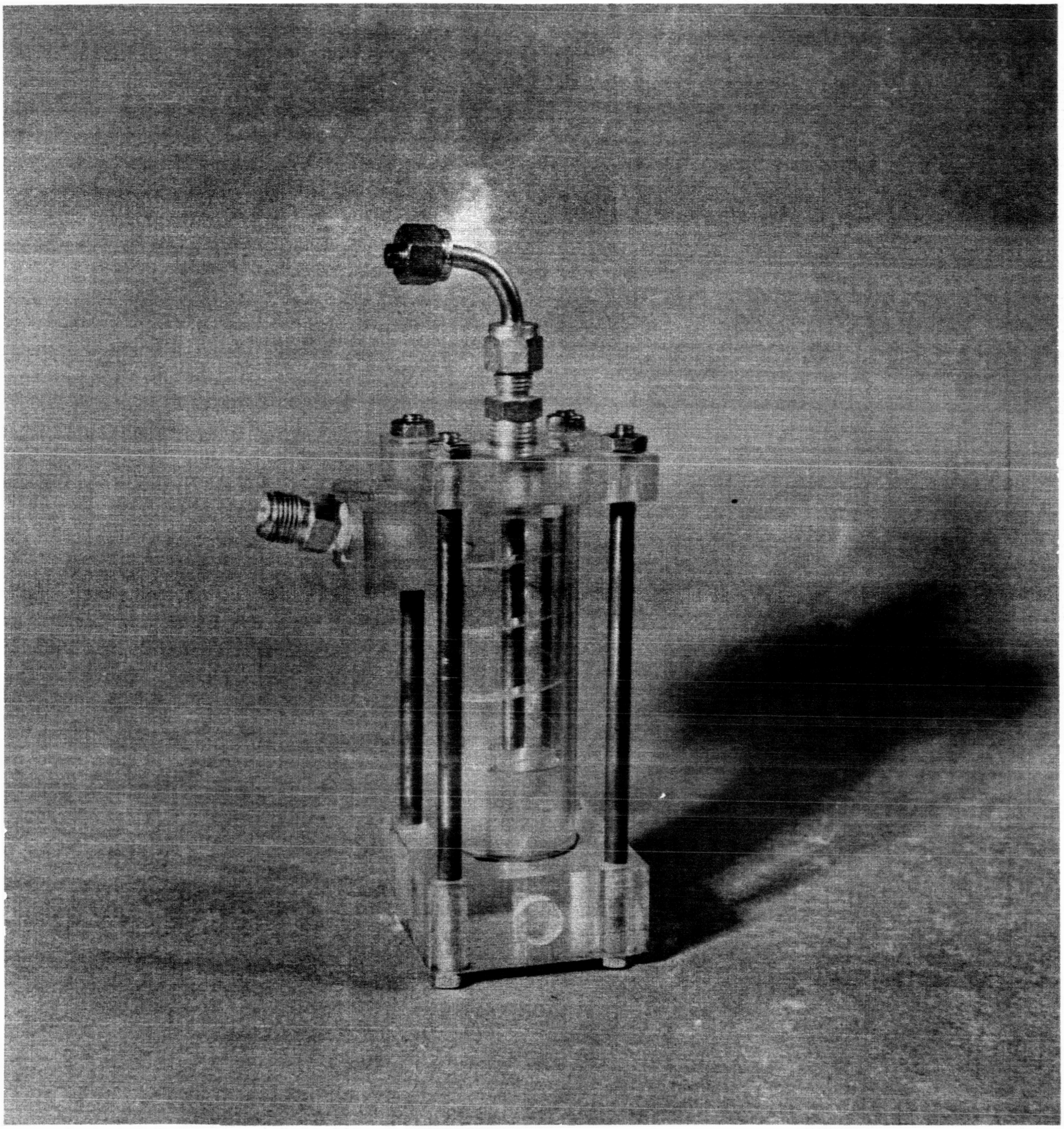
S.A.D.S.
ALLIS-CHALMERS MFG. CO. FIG. 15

4-10-63
J.W.H.



SPIRAL TYPE
GAS & WATER VAPOR SEPARATOR

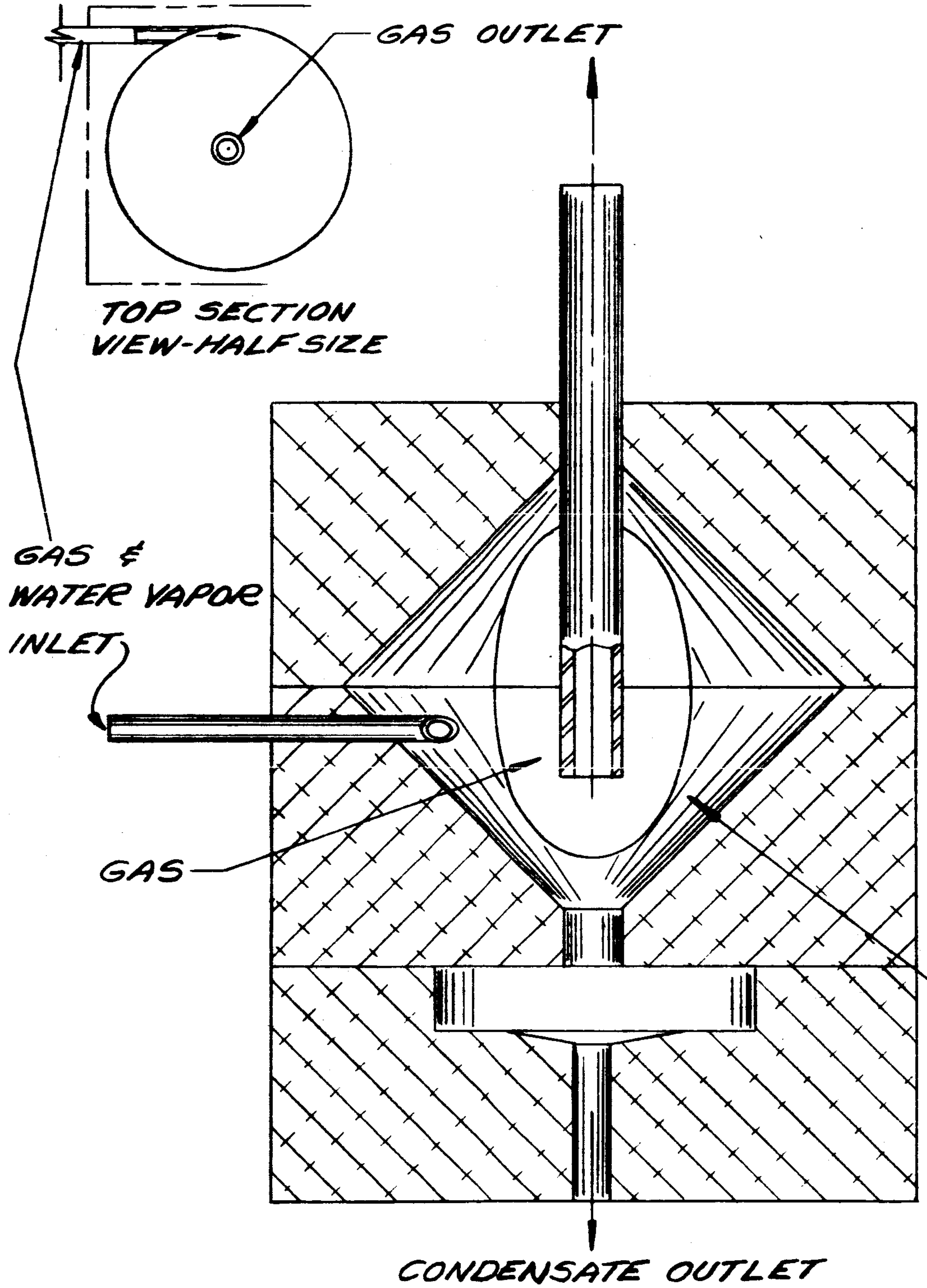
FIG. 16



SPIRAL TYPE

GAS-WATER VAPOR SEPARATOR

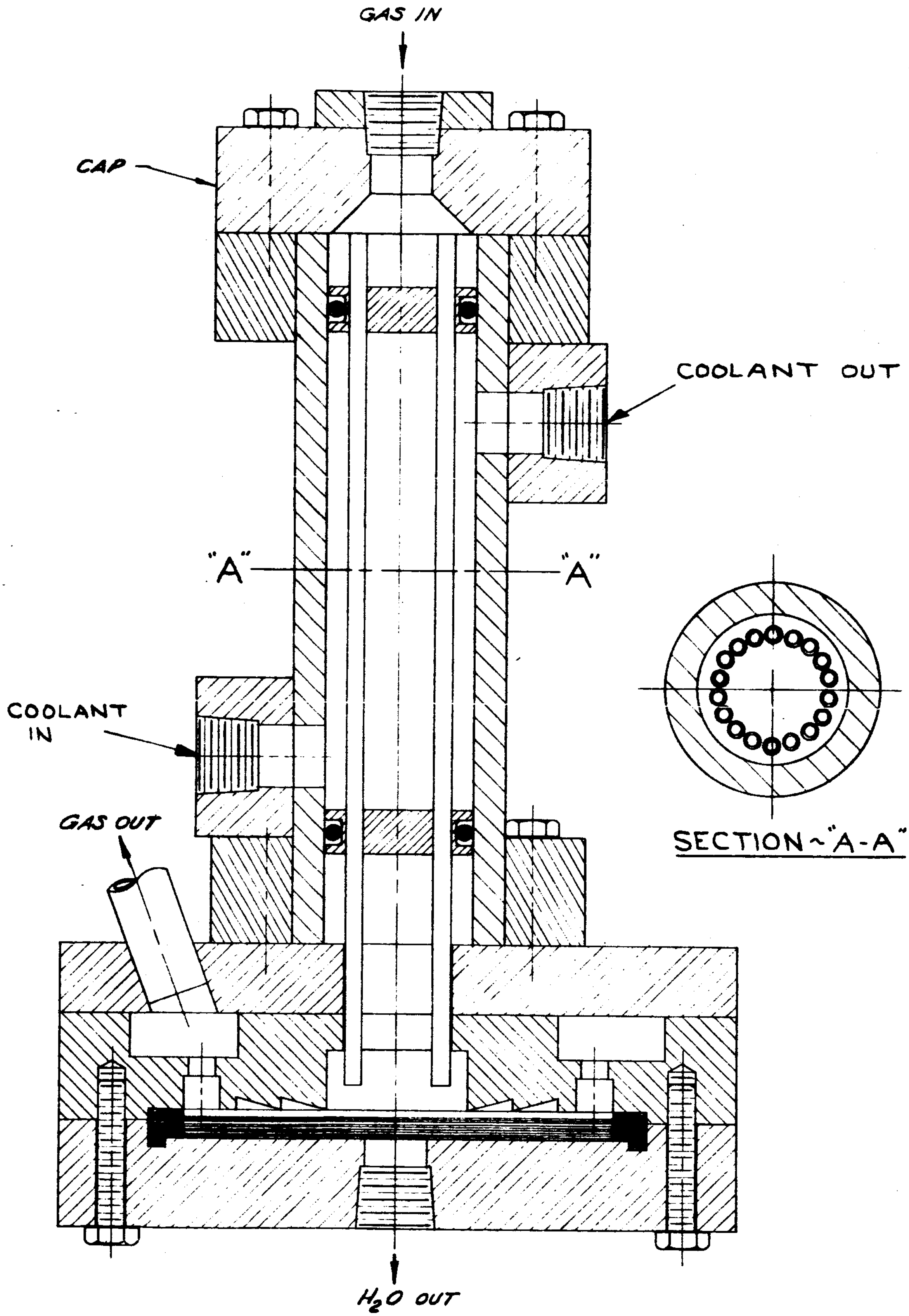
FIGURE 17



CONICAL TYPE SEPARATOR

ALLIS CHALMERS MFG. CO. FIG. Nº 18

1-SK-63087-7
J.H. 1-24-63



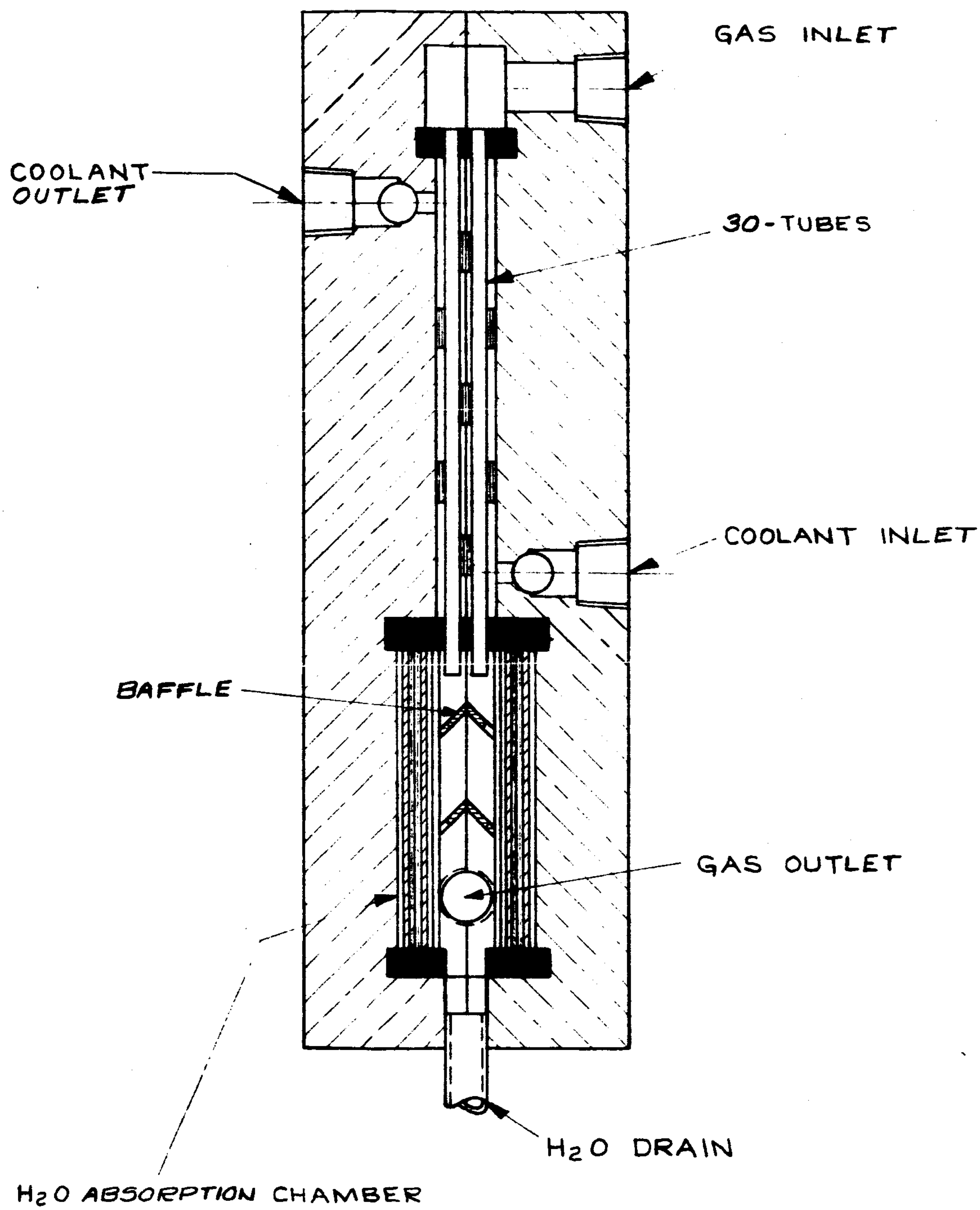
CONDENSER & SEPARATOR ASSY. No. 1

FIG. No 19

ALLIS-CHALMERS MFG. CO.

1-SK-62311-2

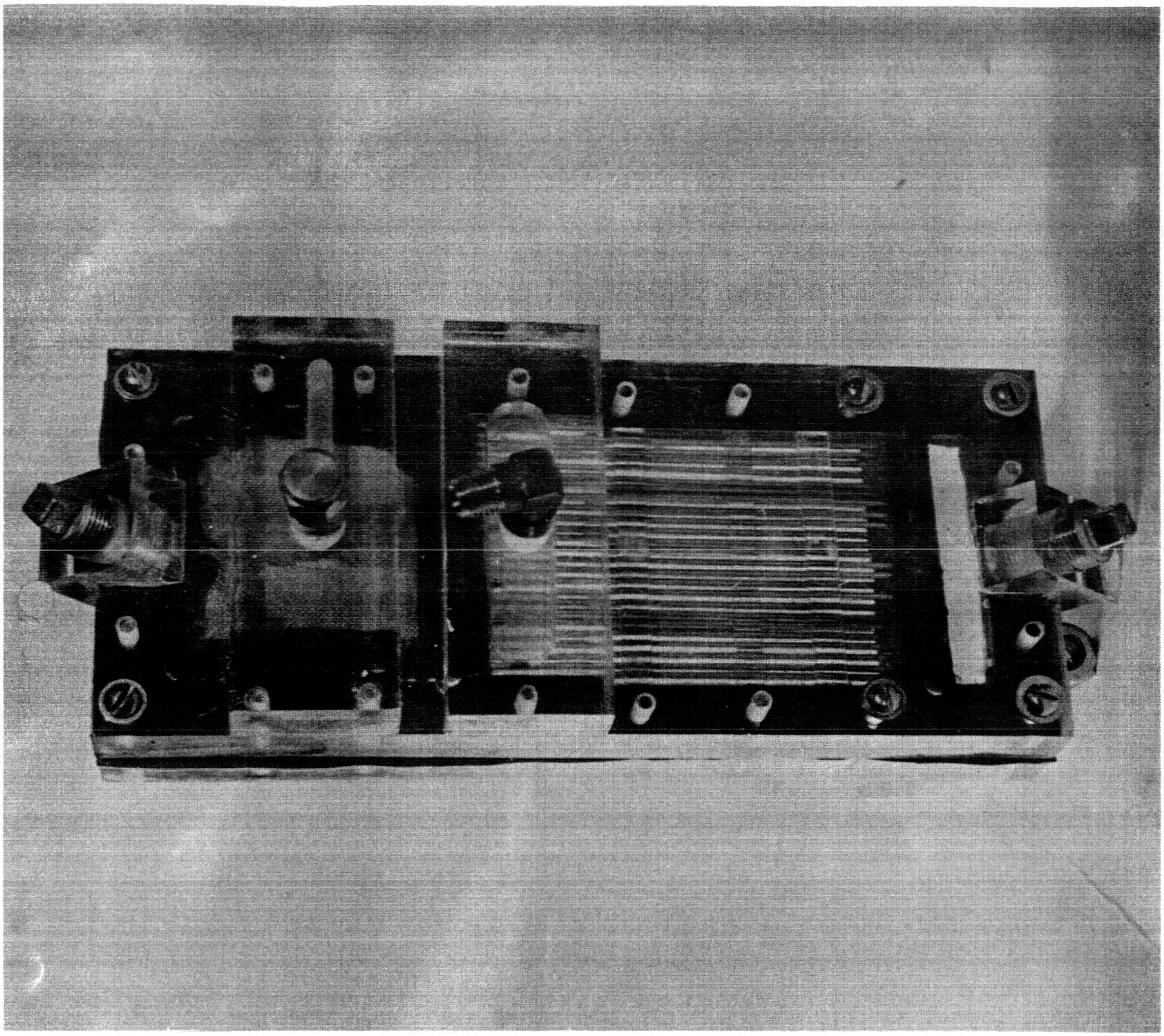
CONDENSER & SEPARATOR ASSEMBLY No. 2



ALLIS-CHALMERS MFG. CO.

FIG. 20

1-30-63 J.H.
1-SK-63087-10



CONDENSER SEPARATOR NO. 2

FIGURE 21

CONDENSER & SEPARATOR ASSEMBLY No. 3

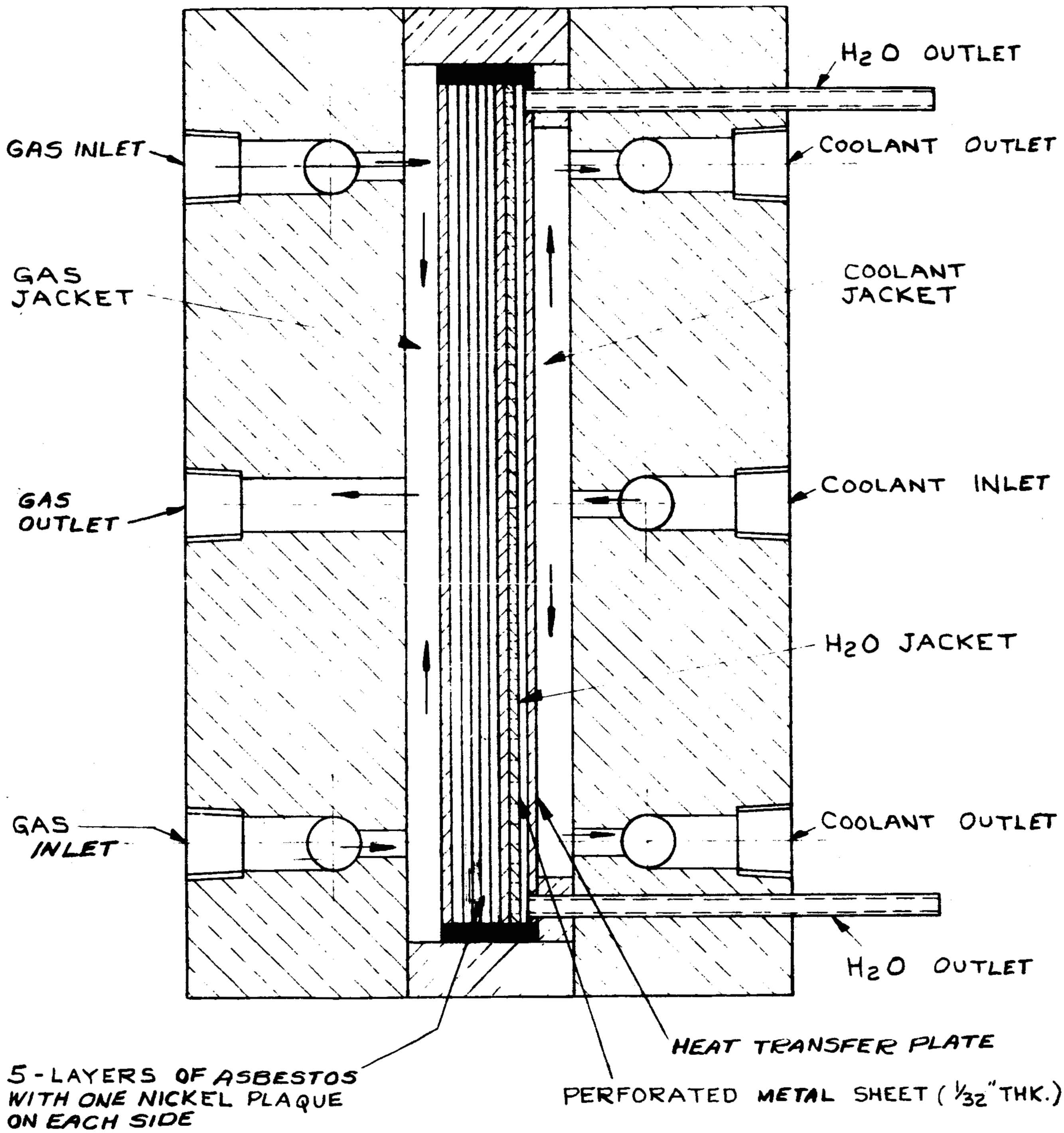
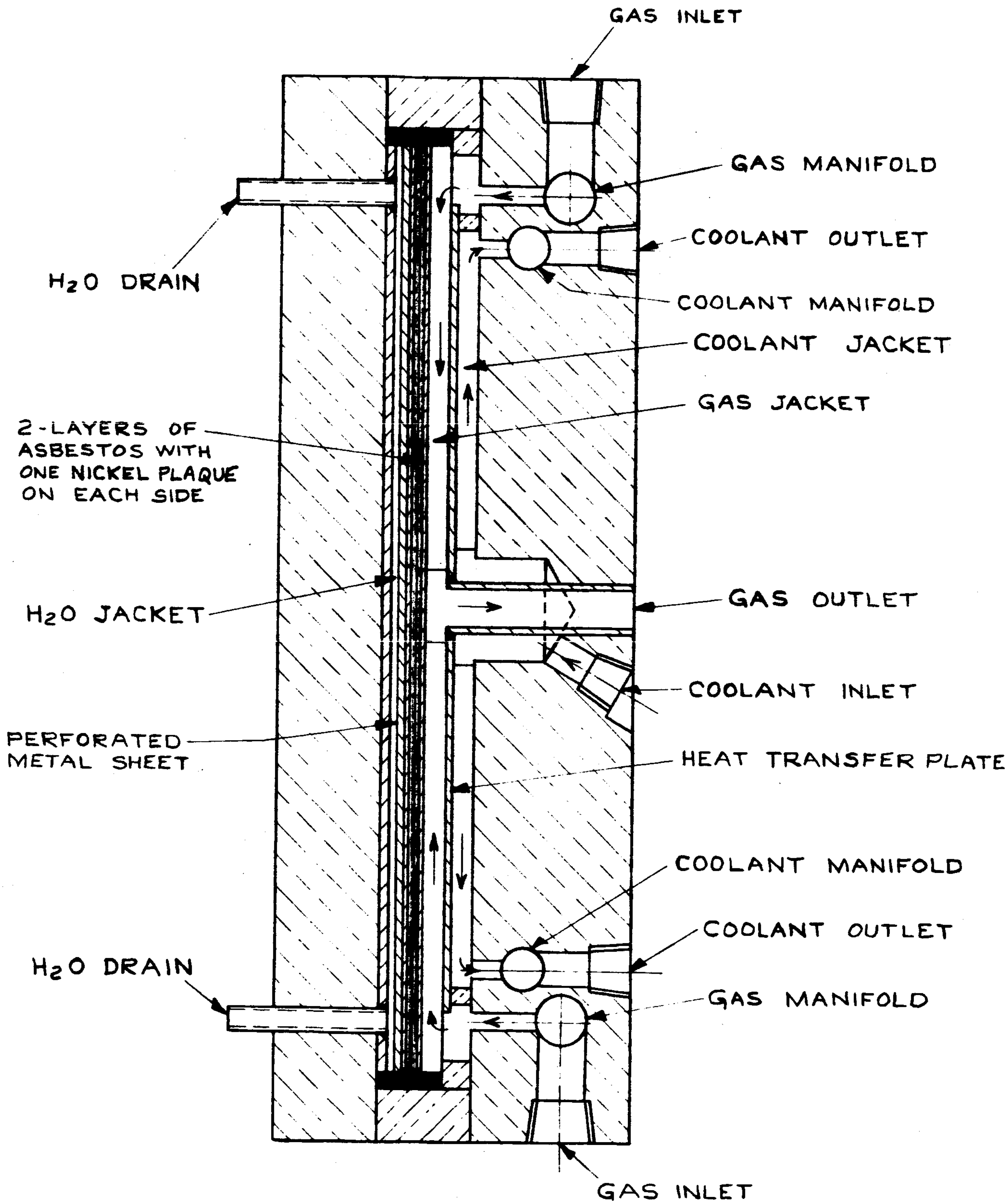


FIG. 22

ALLIS-CHALMERS MFG. CO.

1-SK-63087-11
1-30-63 J.H.

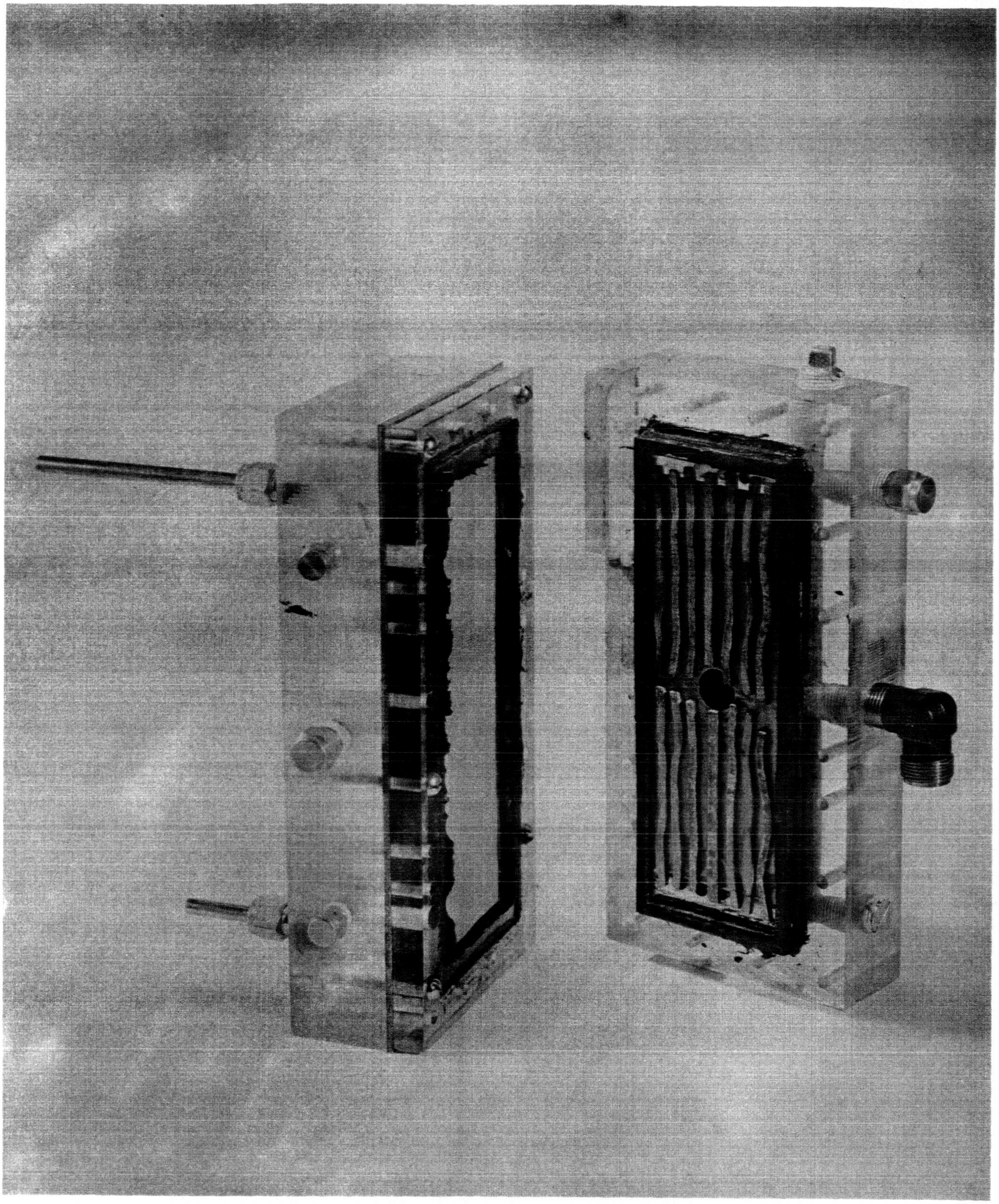
Condenser & Separator Assembly No. 4



ALLIS-CHALMERS MFG. CO.

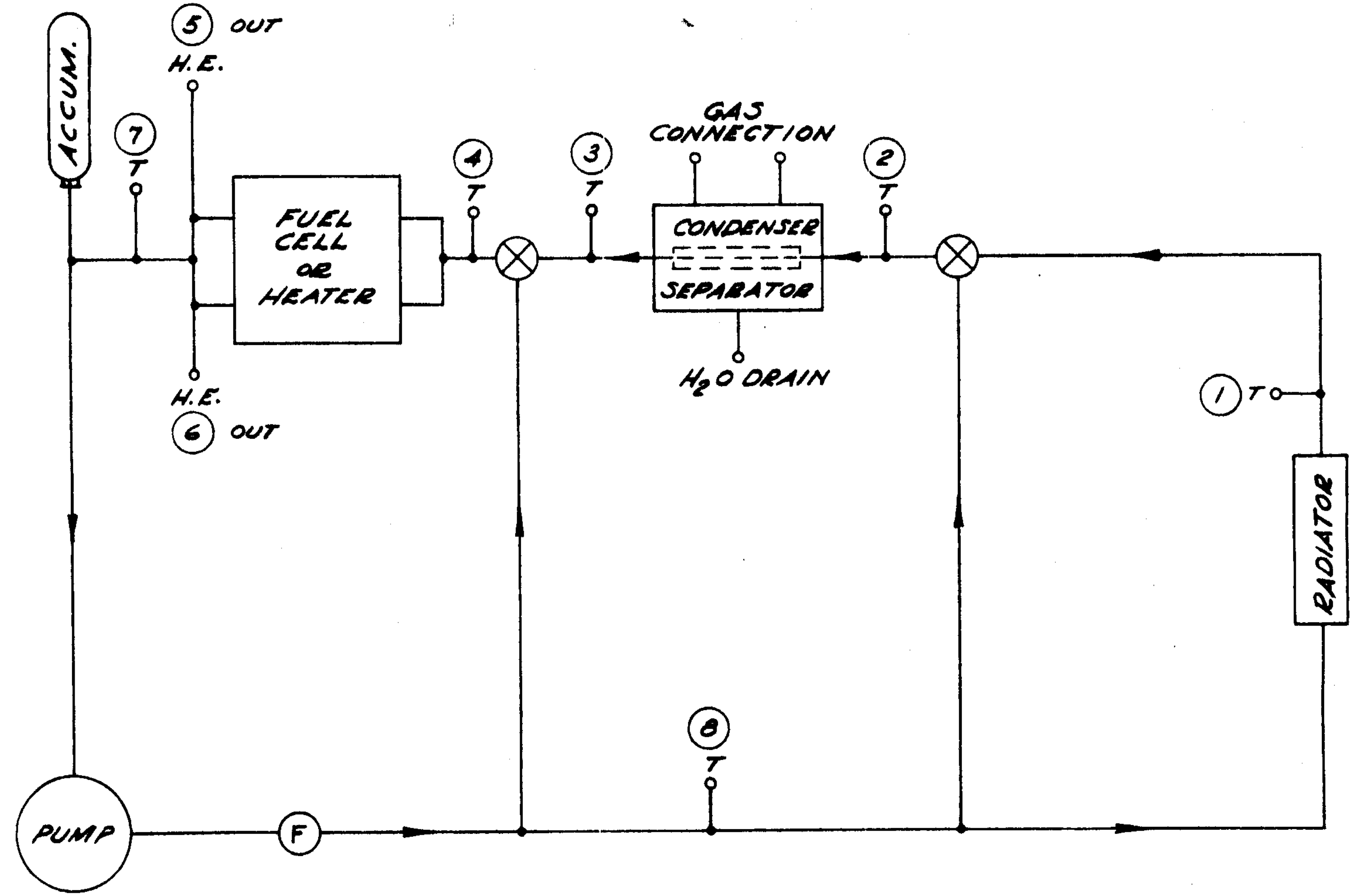
FIG. 23

1-SK-63087-12
1-30-63 K.R.B.



CONDENSER AND SEPARATOR NO. 4

FIGURE 24



MIXING VALVE

F FILTER

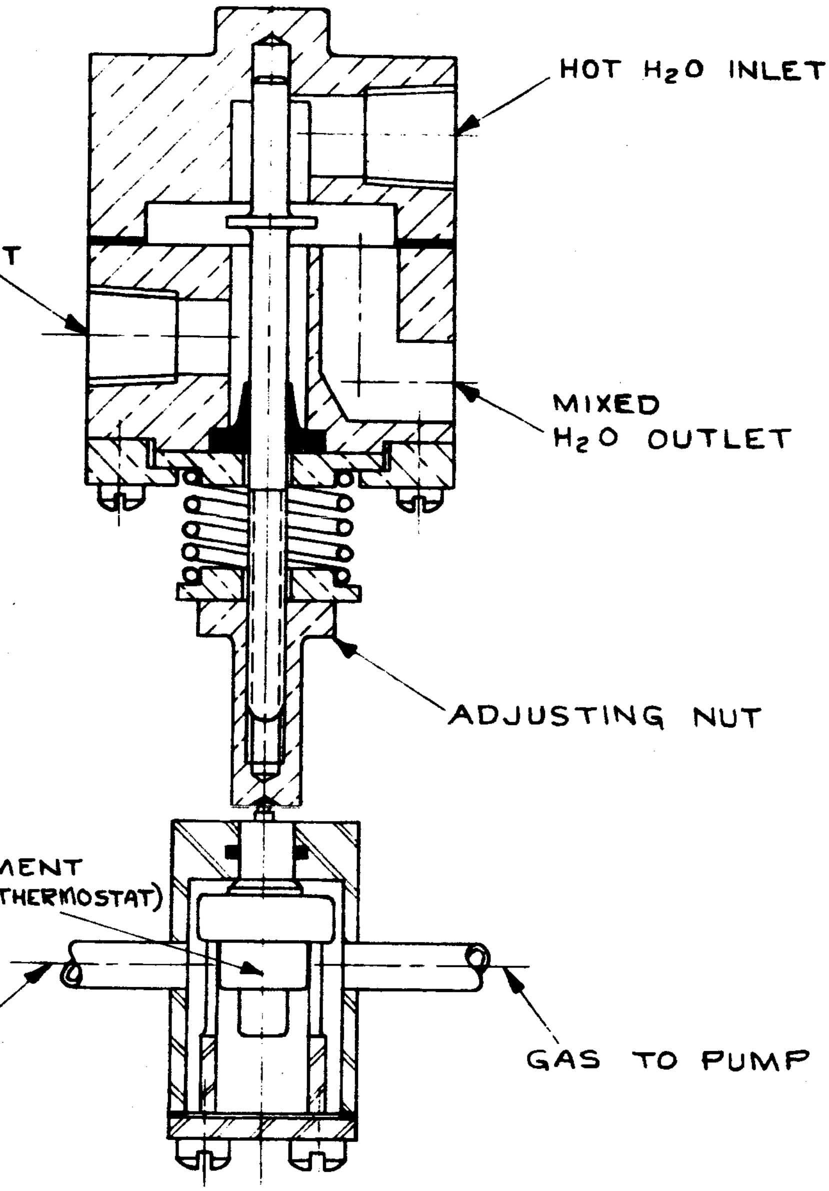
H.E. - HEAT EXCHANGER

T - THERMOCOUPLE

SCHEMATIC OF FUEL CELL COOLING SYSTEM WITH H_2 CONDENSER

FIG. 25

2-21-63 E.L.R.



COOLANT MIXING VALVE
ACTUATED BY GAS TEMPERATURE

ALLIS-CHALMERS MFG. CO. FIG. 26 3-26-63 W.P.B.

1-SK-63087-33